Recycled Chicken Feather Sand as a Partial Replacement for Natural Sand for Producing Eco-Friendly Mortar

Abdel Hafez, Radwa Defalla; Hadzima-Nyarko, Marijana; Ahmed, Samir M.; Tayeh, Bassam A.

buildings

MDPI

Article

Recycled Chicken Feather Sand as a Partial Replacement for Natural Sand for Producing Eco-Friendly Mortar

Radwa Defalla Abdel Hafez [1], Marijana Hadzima-Nyarko [2,3], Samir M. Ahmed [4] and Bassam A. Tayeh [5,*]

1 Civil and Architectural Constructions Department, Faculty of Technology and Education, Sohag University, Sohag 82524, Egypt
2 Faculty of Civil Engineering and Architecture Osijek, Josip Juraj Strossmayer University of Osijek, 31000 Osijek, Croatia
3 Faculty of Civil Engineering, Transilvania University of Brașov, Turnului 5, 500152 Brașov, Romania
4 Civil Engineering Department, High Institute of Engineering, Shrouk Academy, El Shorouk 11837, Egypt
5 Civil Engineering Department, Faculty of Engineering, Islamic University of Gaza, Gaza P.O. Box 108, Palestine
* Correspondence: btayeh@iugaza.edu.ps

Abstract: In this paper, initial experiments were carried out to determine the possibility of using chicken feathers instead of sand in mortar. After earlier research suggested that chicken feathers had a high durability and resilience to degradation, chicken feathers recovered from slaughterhouses were chosen due to the significant cross-linking and strong bonding within their structure. Compared to natural sand, chicken feather sand (CFS) works as an eco-friendly resource. In this study, the chicken feather content ranged from 5% to 25% of the total volume of fine aggregates. The findings confirmed that the compressive strengths of the specimens are inversely proportional to the amount of feathers added. The specimen with 10% CFS had a compressive strength of 57.8 MPa after 28 days of curing. As the weight of CFS in the mortar increased from 1.26% to 10% of the control mixture, the workability significantly decreased. After soaking in water for 24 h, materials with higher proportions of feathers had a noticeably decreased compressive and flexural strength as well as increased water absorption and swelling. For 80% of the CFS replacement, the results are good. Additional CFS replacement tends to reduce the mortar weight.

Keywords: chicken feather sand (CFS); eco-friendly mortar (EM); compressive strength; flexural strength; surface morphology

Citation: Defalla Abdel Hafez, R.; Hadzima-Nyarko, M.; Ahmed, S.M.; Tayeh, B.A. Recycled Chicken Feather Sand as a Partial Replacement for Natural Sand for Producing Eco-Friendly Mortar. *Buildings* **2023**, *13*, 421. https://doi.org/10.3390/buildings13020421

Academic Editor: Jorge de Brito

Received: 7 October 2022
Revised: 6 December 2022
Accepted: 6 January 2023
Published: 2 February 2023
Corrected: 21 August 2024

1. Introduction

Concrete and mortar are both the most popular and expensive materials in the construction industry [1,2]. Many contemporary businesses are having trouble developing an economical and environmentally sound strategy to dispose of waste. The main reasons for this are growing challenges in locating disposal locations and strict environmental policy requirements for waste management and disposal regulations. Each year, the poultry processing industry produces a sizable amount of byproducts, such as feathers that globally weigh 40×10^9 kg in total [3,4]. Legislative requirements and current best practices, such as the Zero Waste Initiative in South Africa, control how this waste is managed, which raises environmental and health concerns [5,6]. Common waste disposal methods, such as incineration, landfilling, and composting, all generate greenhouse gases, use a large amount of energy, and require a large amount of landfill space [7]. Chicken feathers are made up of 91% keratin, 8% water, and 1% lipids [8,9]. The mechanical qualities of chicken feathers are closely linked to their functions, and the mechanical properties are linked to the keratin structure. Keratin's structure enables the transfer of forces with minimal deformation. The elasticity moduli of feather keratin have been observed to vary between 0.045 and 10 GPa. The Young's modulus of oven-dried chicken feather fibers was found to be between 3 and

50 GPa, while the tensile strength was determined to be between 41 and 130 MPa [10]. In response to the growing construction industry, various studies have been performed, particularly in developing countries, to enhance chicken feathers' characteristics and behaviors [11–13]. However, the widespread use of mortar in a wide range of constructions and applications has begun to impose a strain on the environment. Tons of carbon dioxide (CO_2) are released during the excavation, construction, and logistical phases of the cement manufacturing process [14]. Dredging for sand and gravel also pollutes the water, affecting the water level gradient and reducing biodiversity [15]. Kumar Sharma [16] demonstrated that chicken feathers can be utilized as a mortar additive, and it has been claimed that chicken feathers can replace a certain quantity of fine aggregates while maintaining fine aggregate qualities, hence reducing mortar weight. Except for washing and drying them to remove biological contaminants, most research used chicken feathers without any heat treatment before mortar mixing [17]. The compressive strength of the mortar cannot be improved by substituting up to 100% of the sand in the mortar as binder material [18]. Since the use of chicken feather fibers could be possible as part of sand replacement in mortar, this could act as an environmental catalyst leading towards an environmentally friendly mortar [19–22]. Regarding the effects of acids, feathers have a good chemical resistance to mild acids, but since they have a low chemical resistance to strong acids, they disintegrate. Regarding the effect of alkalinity, feathers can withstand moderate alkalinity, but they dissolve under strong alkalinity [23].

This study intends to lower both the environmental effect and the cost of mortar by partially substituting natural sand with the sand obtained from chicken feathers, which is commonly accessible as a waste product in the poultry industry.

First, the chicken feathers were cleaned in water to eliminate waste. The chicken feathers were then dried at room temperature for 24 h before being roasted in an electric oven at 50 °C for 4 h. Finally, the chicken feathers were crushed in an electric grinder. This study aims to improve the compressive strength behavior of mortar by using chicken feather sand (CFS) as a nontraditional, inexpensive, and sustainable sand replacement. This will be performed by comparing the efficacy of CFS to that of natural sand. To accomplish this viewpoint, six conventional mortar mixes were designed and cast; the first mix was the control mix, which was meant to have a strength of 50 MPa. This research examines the performance of modified mortars that employ CFS as a partial fine aggregate replacement at rates of 5%, 10%, 15%, 20%, and 25%. A consistency test was used to control fresh mortar qualities, while water absorption, unit weight, compressive strength after 7 and 28 days, and flexural strength tests were used to control hardened mortar properties. Finally, microstructural analyses were performed to confirm and validate earlier test results.

2. Research Significance

This study suggests that sand derived from recycled chicken feather waste has the potential to be used as a natural, low-cost, and long-lasting partial sand replacement in green mortar while lowering weight. The use of this waste can contribute to a reduction of air pollution, which is hazardous to the environment. Based on the importance of the study in the current work, the following conclusions may be drawn:

- The significance of this research lies in the analysis of chicken feather waste, which has never been thoroughly investigated.
- Use of CFS as a partial replacement for natural sand in the production of eco-friendly mortar (GM).
- Further research is being conducted on the use of CFS as a partial replacement for sand in the eco-friendly mortar industry.
- Eco-friendly mortar production with varying levels of CFS achieved a compressive strength of 57.8 MPa after 28 days.
- Exploring the impact of CFS on the microstructure of eco-friendly mortar (GM), as well as its new and mechanical properties.

3. Experimental Program

3.1. Materials Used and Their Properties

The following materials were used in this research:

- Cement: All mortar combinations were made using standard Portland cement CEM I 42.5 (Asyut cement), which complies with ECP 203.
- Fine aggregate: Local sand was used as the fine aggregate. The sand used is of medium quality. Figure 1 depicts the grain size distribution for CFS, natural sand, and the fine aggregate used in this experiment. The fine aggregate utilized in this experiment was natural siliceous sand, a clean and rounded fine aggregate with a size of 0.5 mm, a specific gravity of 2.66, a unit weight of 1680 kg/m^3, and a fineness modulus of 2.75.
- Water: Potable water was used.

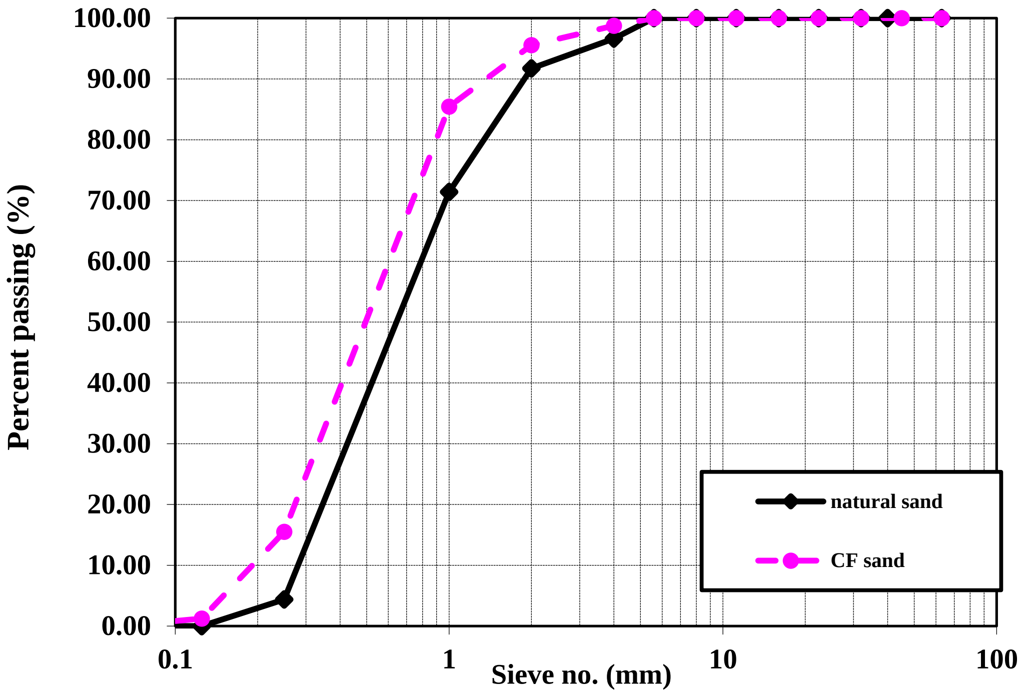

Figure 1. Passing percentage of aggregates utilized (natural and CF sand).

3.2. Chicken Feather Sand

Proportion of Chicken Feather Sand

For this investigation, one form of CFS was proposed. To increase the strength of the mortar mixes, CFS was added. The discarded chicken feathers were provided by poultry farms. The combustion of such waste can contaminate the air and endanger the ecosystem. Before casting cement with CFS as a sand replacement, the feather surface must be cleansed to remove dirt and other unwanted particles. To remove blood, discarded feathers were taken in bags to the laboratory and washed many times with water. The clean feathers were then spread out on sheets to dry for five days in the sun, as shown in Figure 2, and they were not chemically treated. An electric oven was then used to roast the samples at a temperature of 50 °C for four hr. before being crushed in a commercial electric grinder. Table 1 lists the physical and mechanical characteristics of chicken feathers, and Figure 2 depicts the steps for chicken feather sand preparation.

Figure 3A depicts a photograph of a chicken feather, and Figure 3B shows sand (CFS) made from chicken feathers. More than 90% of the protein in chicken feathers is a fibrous and insoluble structural protein. The chicken feather has good resiliency because it has cross-section gaps. Saving money, helping to build a more sustainable environment, and increasing the sand market are all benefits of using chicken feathers. Table 2 shows the elemental composition of a chicken feather (CF).

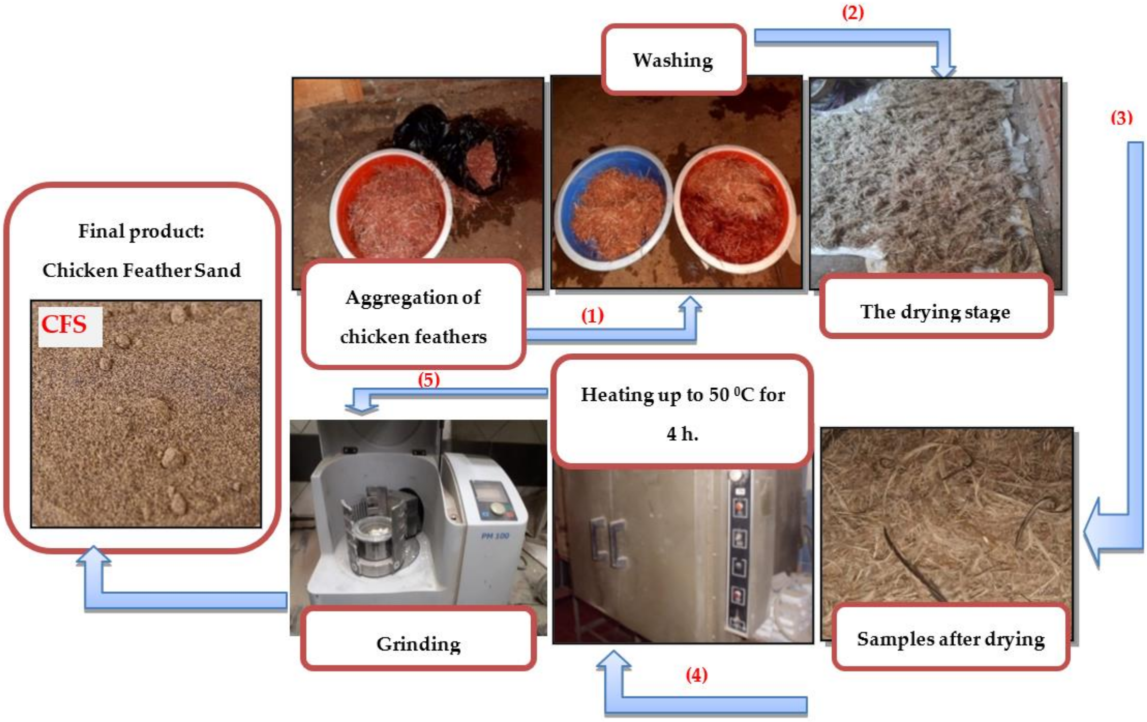

Figure 2. The process of preparing sand from chicken feathers.

Table 1. Physical properties of the chicken feathers (CFs).

Physical Properties	Chicken Feather (CF)
Elongation at Break (%)	1–6
Modulus of elastic (G/tex)	3.96
Moisture Content (%)	10–11
Moisture Regain (%)	12–12.35
Density (t/m^3)	1.12

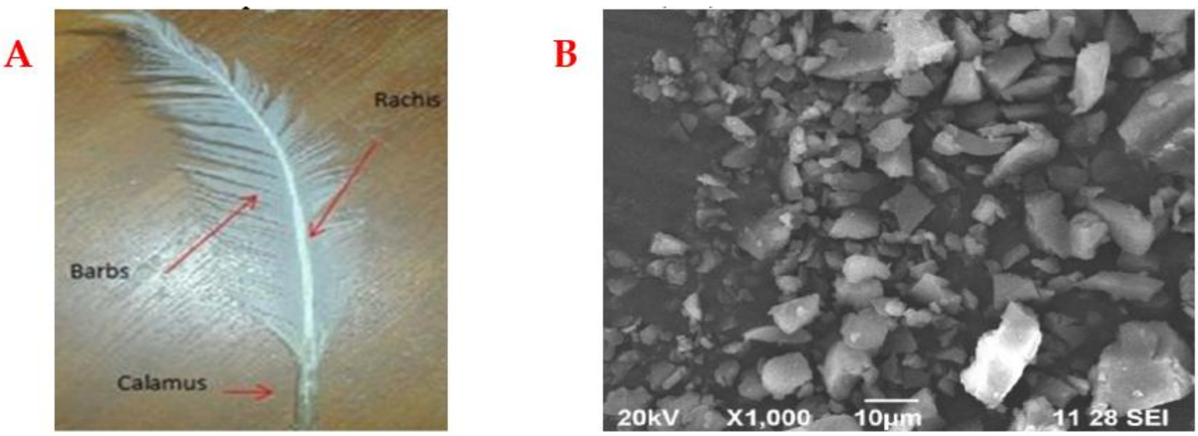

Figure 3. (**A**) Photograph of a chicken feather showing rachises and barbs. (**B**) SEM image of chicken feather sand [24,25].

Table 2. Elemental composition of a chicken feather (CF).

Elements	K	Mg	Ca	Na	P	S	Fe	Mn	Zn	Cu
CFP (g 100 g^{-1})	12.52	5.31	6.58	7.96	2.16	0.04	0.95	0.62	0.77	0.22

4. Mix Design Proportions

Table 3 shows the details of the mixing proportions for mortar with grade 50 MPs (M 50). To ensure a consistent mixing technique for the specified ratio, physical parameters of the components, such as specific gravity, water absorption, and moisture content, were taken into consideration throughout the design mix process. The different percentages of CFS replacement were determined based on the literature. The manual method was used to design the mortar mix. The fine aggregate is substituted with CFS in various amounts, such as 0%, 5%, 10%, 15%, 20%, and 25% natural sand. According to a previous study, aggregate replacement rates of 5%, 10%, and 15% produced the best results in terms of strength. To ensure homogeneity, the cement, CFS, and aggregates were mixed dry, and water was gradually added. The cubes and prisms were cast in molds and allowed to cure for 7 and 28 days for cubes and 28 days for prisms at room temperature before being tested.

Table 3. Mix design proportion (kg/m^3).

Sample	Cement	Sand	CFS	Water
C-0.0%	528.0	1584.0	0	211.20
CFS-5%	528.0	501.6	26.4	211.20
CFS-10%	528.0	475.2	52.8	211.20
CFS-15%	528.0	448.8	79.2	211.20
CFS-20%	528.0	422.4	105.6	211.20
CFS-25%	528.0	396.0	132.0	211.20

5. Testing Procedure

Six different cement mortars with varying CFS replacement ratios were designed and prepared following BS EN 196-1 [26] to measure and compare the physical and mechanical properties of cement mortar.

Eighteen tests were conducted to determine the consistency of the fresh mortars. Thirty-six cube specimens with dimensions of 70 × 70 × 70 mm were prepared and cured to conduct compression tests after 7 and 28 days, respectively, as shown in Figure 4, while flexural strength tests were conducted using eighteen prismatic specimens with dimensions of 40 × 40 × 160 mm and tested using a three-point testing device at a curing age of 28 days, as shown in Figure 4. All tests were carried out in accordance with the BS EN 196-1 standard [26].

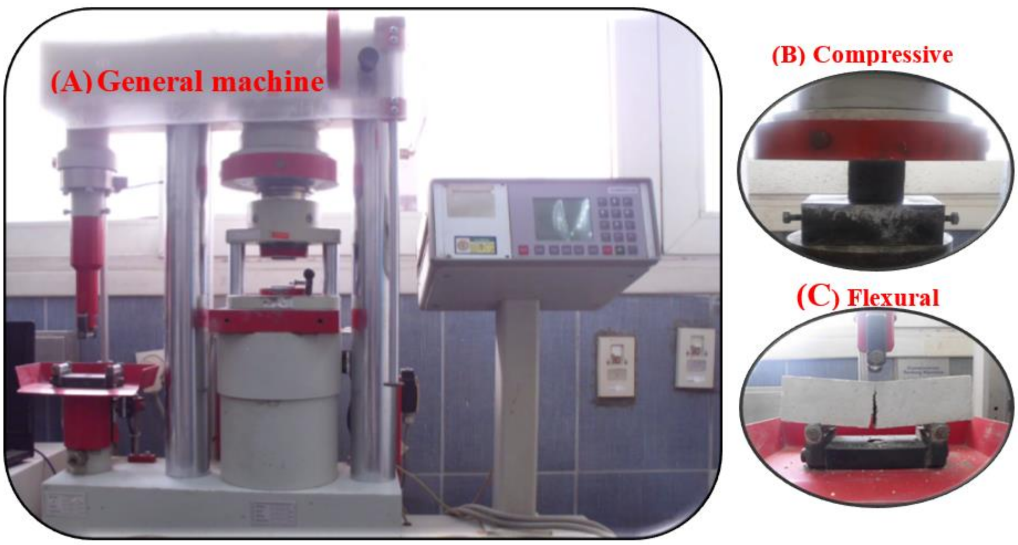

Figure 4. View of testing: (**A**) machine, (**B**) compressive strength, and (**C**) flexural strength.

The strength of the mortar can be dramatically affected when natural sand is substituted with CFS. As a result, it is important to determine if the mortar structure and its components have unraveled or remain solid. Microstructural characteristics for the control and replacement specimens were obtained using a scanning electron microscope (SEM) at a high magnification power, as shown in Figure 5.

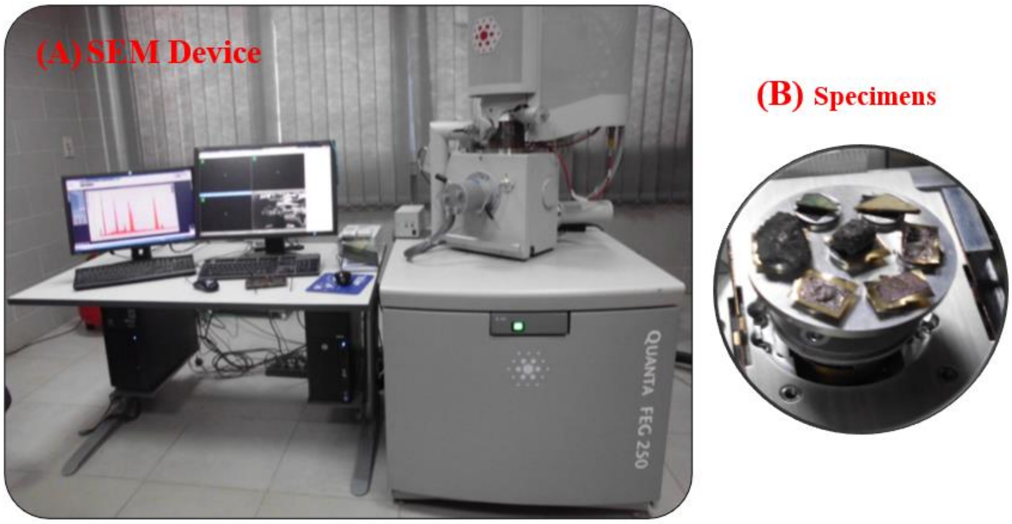

Figure 5. The view of (**A**) scanning electron microscopy (SEM) device; (**B**) specimens.

6. Test Results and Discussions

The physical and mechanical properties of the CFS mortar were examined. The results of the experiment are summarized in Table 4, which includes consistency, unit weight, water absorption, compressive strengths at 7 and 28 days, flexural strength, and microstructural analyses.

Table 4. Properties of the CFS mortar.

Sample	Consistency (mm)	Unit Weight t/m^3	Water Absorption (%)	F_{cu} at 7 Days (MPa)	F_{cu} at 28 Days (MPa)	Flexural Strength (MPa)
C-0.0%	152	2.53	7.2	36.7	51.0	9.2
CFS-5%	147	2.50	8.2	39.6	55.1	10.1
CFS-10%	141	2.46	9.4	41.6	57.8	10.7
CFS-15%	134	2.41	10.6	37.9	52.1	9.5
CFS-20%	126	2.35	11.8	33.3	46.1	8.3
CFS-25%	117	2.28	12.9	28.2	38.6	6.9

6.1. Fresh Properties

In this study, mixtures were prepared with a constant water-to-cement ratio (W/C) of 0.4 and replacement ratios of CFS of 5%, 10%, 15%, 20%, and 25%. Furthermore, when compared to the control sample, a higher replacement of CFS resulted in a lower workability for the same quantity of water, as represented in the consistency value of the blended cement paste, as shown in Figure 6. These findings are comparable with those of Abishek et al. [27]. The CFS-5%, CFS-10%, CFS-15%, CFS-20% and CFS-25% mixtures had approximately 3.29%, 7.24%, 11.48%, 17.11%, and 23.03% lower consistencies than the control mixture, respectively. The reduced water requirement of CFS is due to the substance's ability to absorb water when compared to natural sand, as well as the microstructure of the substituted mixtures [16,28]. Because a high replacement ratio requires the use of more water to achieve a specific consistency, more water is required to maintain that consistency.

On the other hand, low replacement ratios are ineffective at this time. This conclusion was consistent with the findings of other studies, see Figure 6 [29].

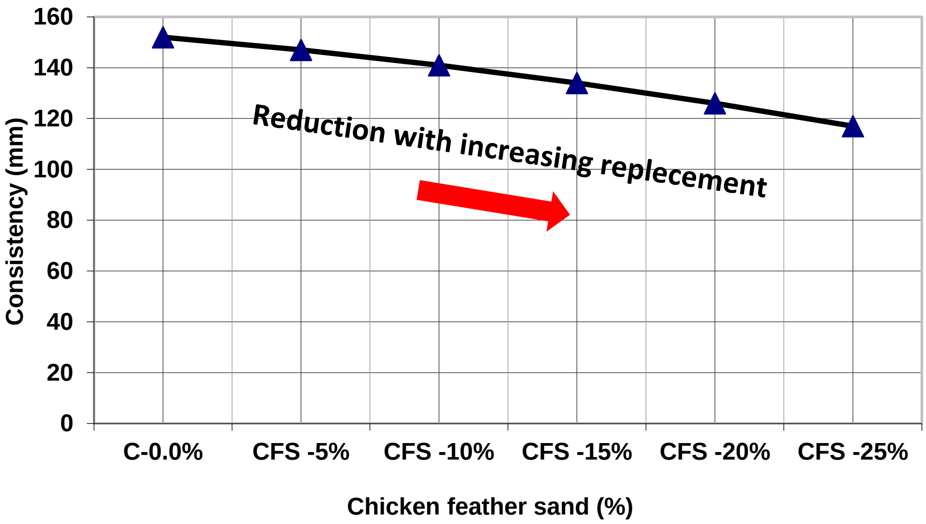

Figure 6. Consistency values for all mixtures.

For a high CFS replacement, this is attributed to the fact that some portion of the mixing water is absorbed by CFS. As a result, a greater amount of super-plasterer was necessary to compensate for the reduction in water volume to enhance workability with high replacement ratios greater than 20%. Many investigations have confirmed that replacing CFS in mixtures necessitates the use of more super-plasterers to maintain workability [30].

6.2. Hardened Properties

Figure 7 shows the compressive and flexural tests, and the relationships between the compressive strength, unit weight, and replacement percentage are shown in Figure 8. The unit weight of all mixes, C-0.0%, CFS-5%, CFS-10%, CFS-15%, CFS-20% and CFS-25%, ranged from 2.53 to 2.28 t/m^3. The conclusion is that mortars combined with lightweight aggregates have lower masses as a result of an increased void content. Increasing the replacement proportions resulted in a 10% reduction in the mortar unit weight for the CFS mixes. The results are consistent with [31]. According to Figure 8, the relationship between the compressive strength and unit weight is proportional, which means that the greater the compressive strength is, the lower the weight at the replacement ratio CFS-10% is, and the lower the compressive strength is, the lower the weight after the replacement ratio CFS-10% is [32].

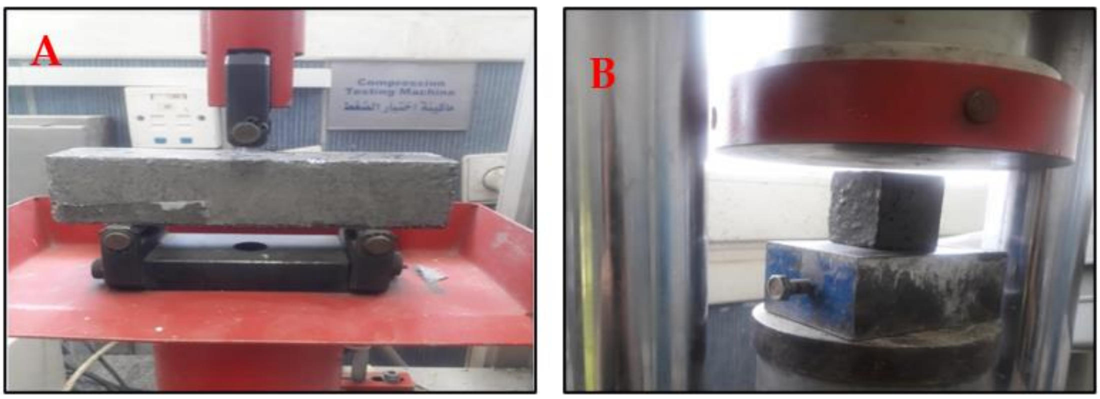

Figure 7. (**A**) Compressive test. (**B**) flexural test.

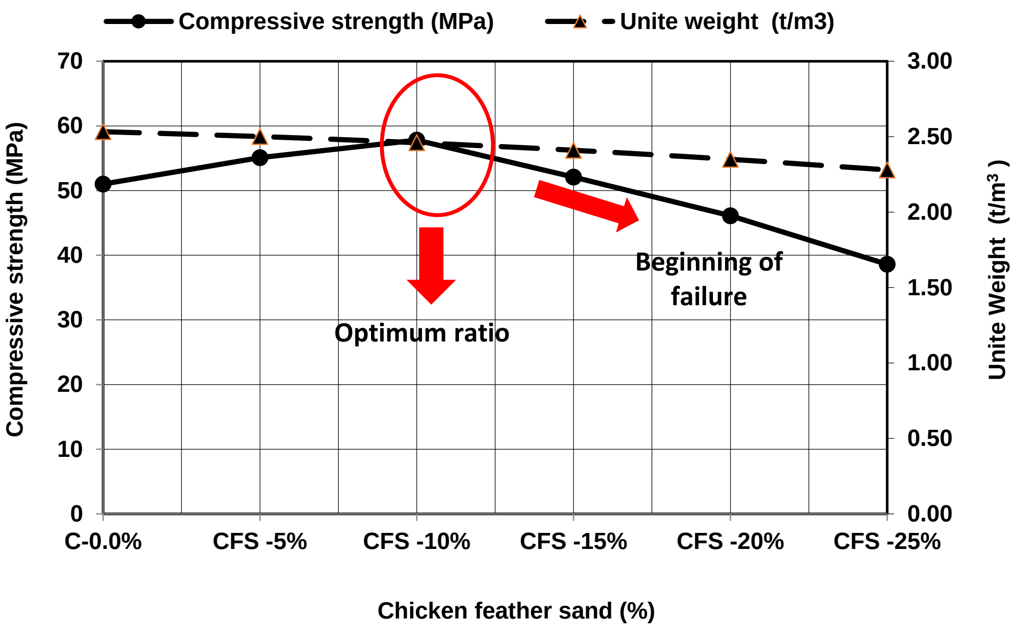

Figure 8. The relationship between compressive strength and unit weight depends on the replacement percentage.

To investigate the dimensional stability of bio-composites, all samples were immersed in water at 25 °C for 48 h. Figure 9 shows how much water was absorbed after 48 h of immersion in water. Because of CFS's great absorption capacity, very high results were expected. After 48 h of immersion, all the samples acquired water in the range of 13.90% for CFS-5% to 79.17% for CFS-25%. It can be observed that the water absorption increases as the CFS replacement increases. The water absorption was the highest for the CFS-25% mixture. These findings are consistent with those reported by Ouahiba Mrajji et al. [33,34], who found that adding CFS to mortar mixes improved water absorption and reduced compressive strength [35–37].

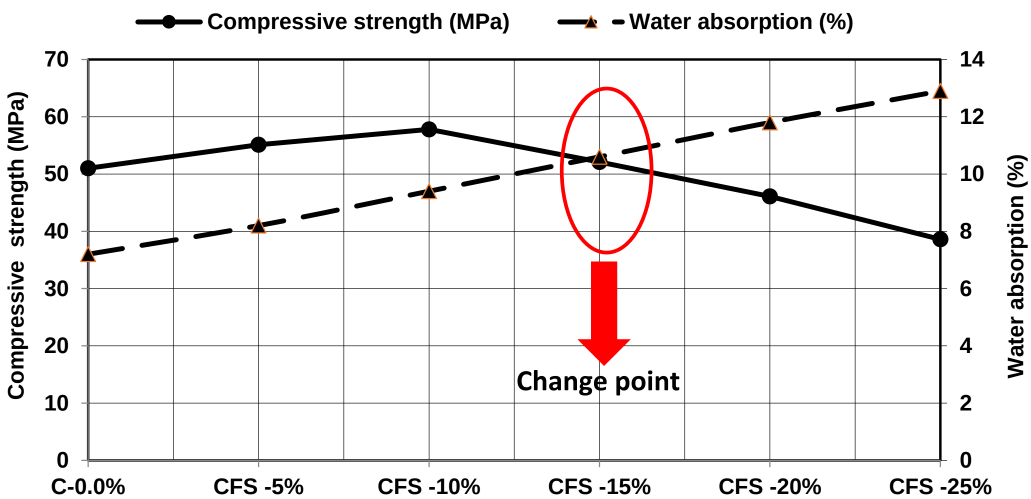

Figure 9. The relationship between compressive strength and water absorption (%) depends on the replacement percentage.

Figure 10 depicts the compressive strength values of CFS mixes depending on the amount of CFS replacement. The CFS-10% combination attained the ultimate compressive strength. The increase in compressive strength at 7 days was found to be highly apparent in comparison to the increase in compressive strength at 28 days, which ranged from 2.16% to 13. 33%. The usage of CFS from 5% to 15% of a fine aggregate contributed significantly to the compressive strength values. As a result, the inclusion of 10% CFS as the optimal replacement ratio resulted in a 41.58 MPa compressive strength at 7 days and 57.8 MPa compressive strength at 28 days [16,38,39].

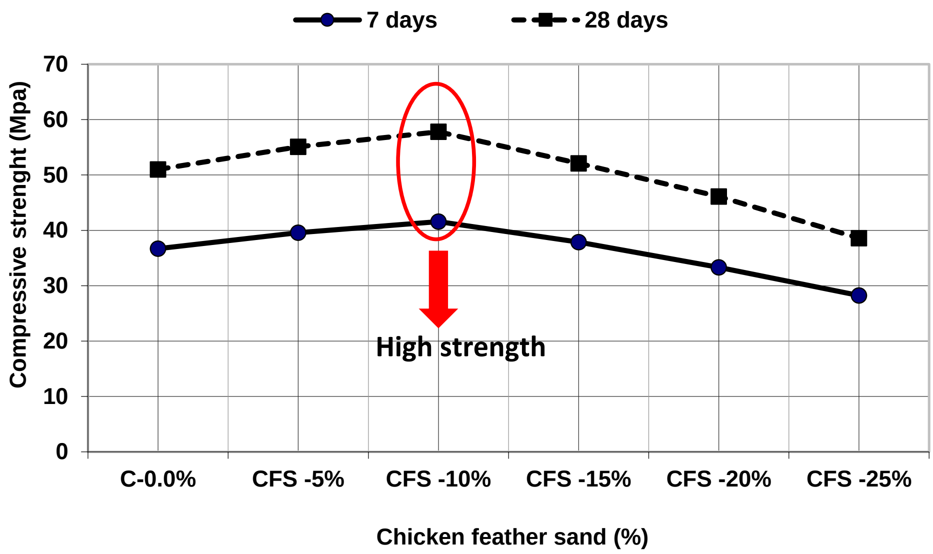

Figure 10. The values of compressive strength at 7 and 28 days for all mixtures.

Figure 11 shows the flexural strengths of mixtures with and without replacement, as well as the flexural/compressive (F/C) ratios. According to the findings of this study, using CFS in specific amounts greatly enhances flexural strength. Mechanical characteristics were reduced with a 15% CFS replacement. The compressive strength increases with a stronger matrix, and high flexural strengths can be achieved [40]. It is assumed that at a certain level of CFS (10% by weight), the weak bonding capability of CFS diminishes the adhesive strength with paste, resulting in low mechanical properties, as documented in the literature [41,42]. The F/C ratios ranged between 18.51% for the CFS-10% mixture and 17.88% for the CFS-25% mixture. The CFS replacement in mortar improved mechanical properties such as the compressive strength, flexural strength, and other properties, and this result is in agreement with the reference [16,43]. Figures 12 and 13 show the standard deviations for compressive and flexural strengths.

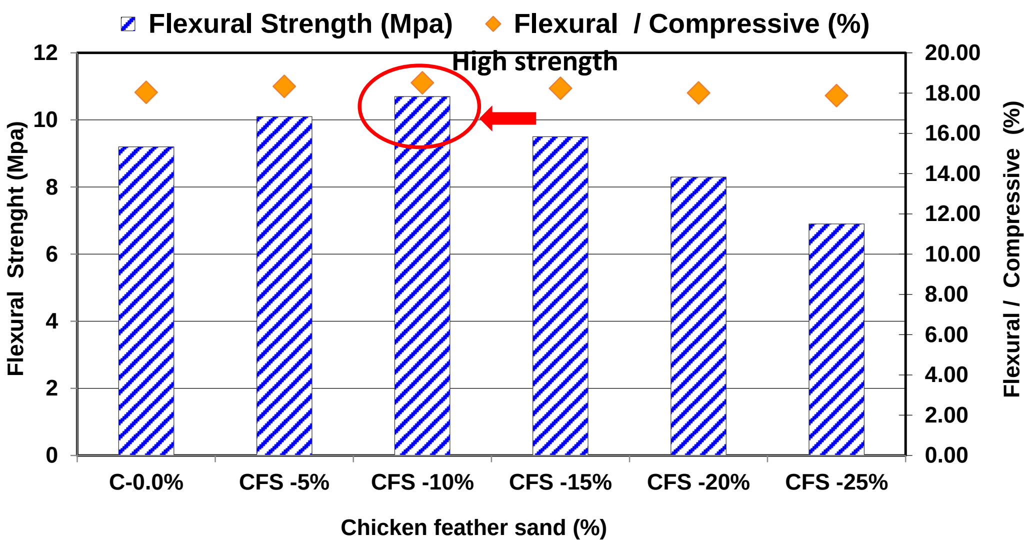

Figure 11. The relationships between flexural strength and flexural/compressive strength (%) depending on the replacement percentage.

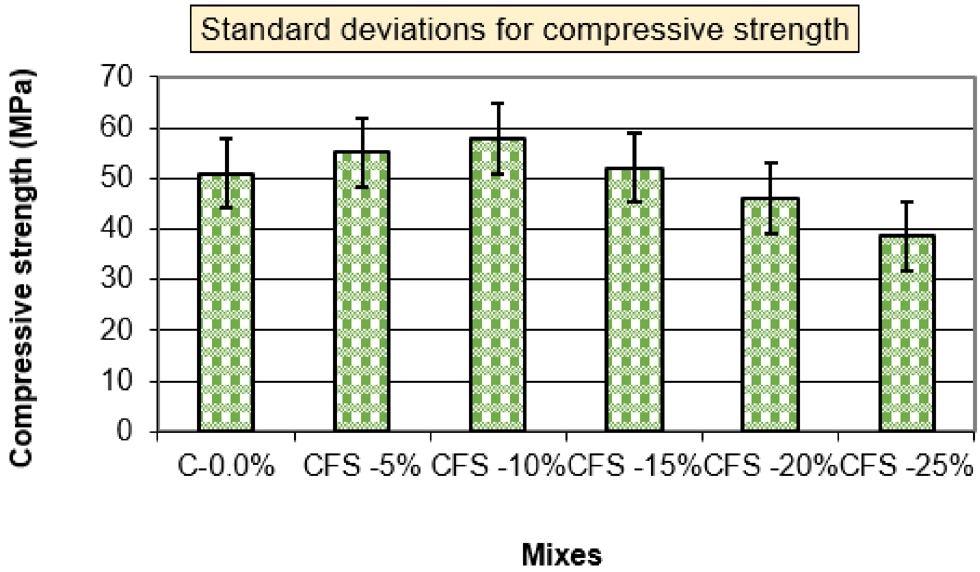

Figure 12. Standard deviations for compressive strength.

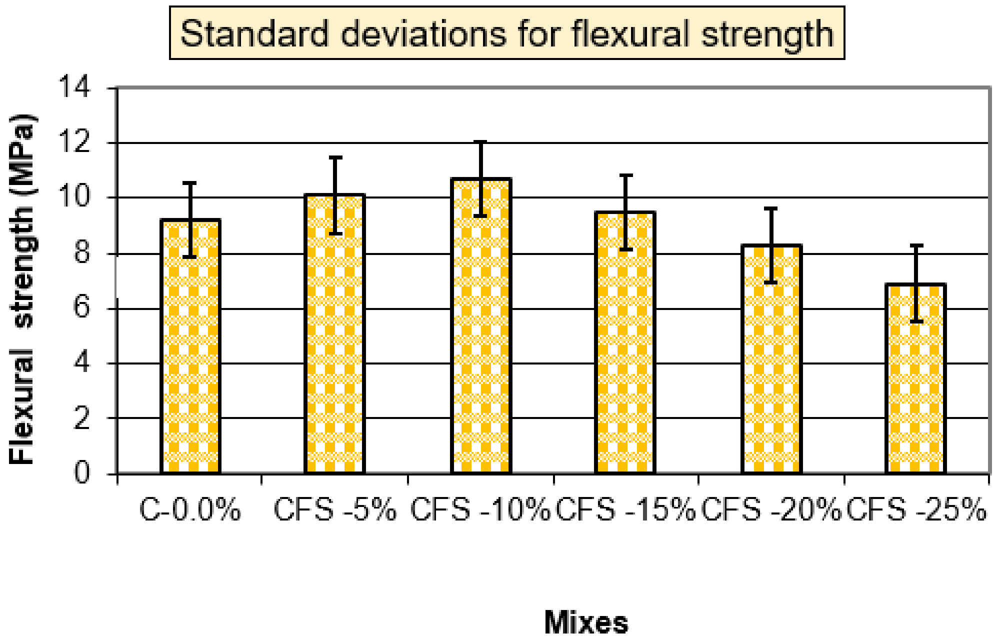

Figure 13. Standard deviations for flexural strength.

6.3. Surface Morphology

The micrographs of the CFS mortar are shown in Figure 14. According to Figure 14, the structure of the CFS particles varied. The surface texture and shape of the mortar varied due to the replacement ratios. The densification of the particles is influenced by grade 50 MPa mortar, as shown in the microstructure (Figure 14a–d). The surfaces of the CFS-5%, CFS-10%, and CFS-15% mixtures are rigid and nonporous, but the surfaces of the CFS-20% and CFS-25% mixtures are porous. This rigid surface may contribute to a better strength (Figure 14b–d), while the porous surface provides a lower strength (Figure 14e,f) due to the dispersion structure [44,45]. The surfaces of the CFS-20% and CFS-25% mixtures are rigid, whereas the CFS-5%, CFS-10%, and CFS-15% mixtures have smooth surfaces. The high replacement of fine aggregates indicates a non-uniform dispersion of the fillers within the matrix [46,47]. The appearance of clusters is a clear indicator that the CFS agglomerated in the mortar at large replacement ratios (20% and 25%). In contrast, the surfaces of the

CFS-5%, CFS-10%, and CFS-15% mixtures have fewer clusters. These findings suggest that the interfacial bonding is stronger between the CFS and mortar in low replacements [48–50].

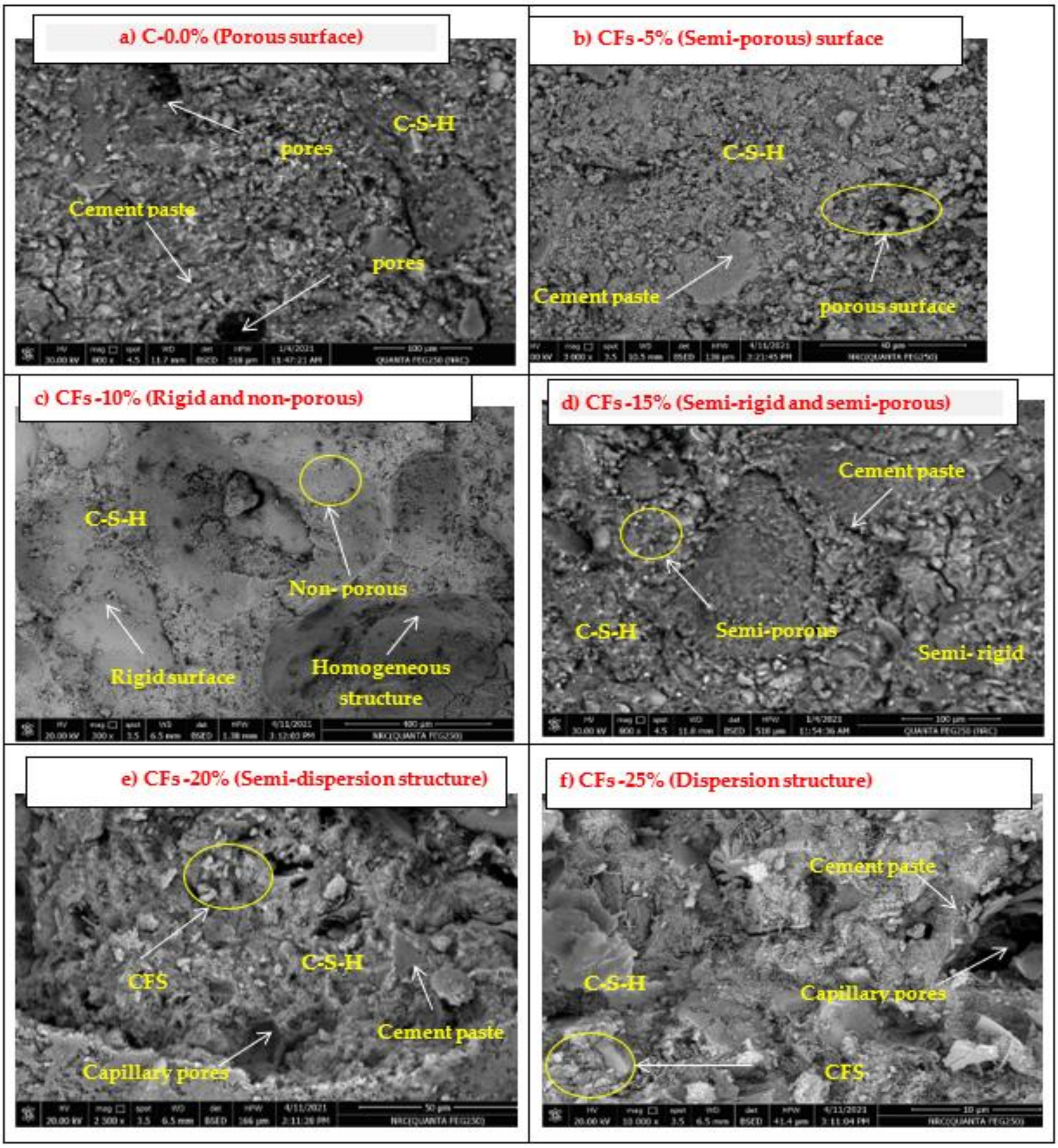

Figure 14. SEM micrographs of the samples: (**a**) C-0.0%, (**b**) CFS-5%, (**c**) CFS-10%, (**d**) CFS-15%, (**e**) CFS-20%, and (**f**) CFS-25%.

6.4. Comparison between Natural Sand Mortar and Chicken Feather Sand Mortar Cost

A cost comparison was performed, and it was revealed that replacing 15% of the sand costs the least and has the greatest impact on the project's cost. However, according to this research, the optimal replacement is 10%, which reduces the cost of 1 m^3 of mortar by 3.0% and simultaneously increases the strength, which is in accordance with references [1,51,52].

It must be noted that the comparison of the cost did not include the cost of admixtures, mixing, and casting of the mixes, which can be assumed to have similar costs for the studied types of mortar (see Figure 15).

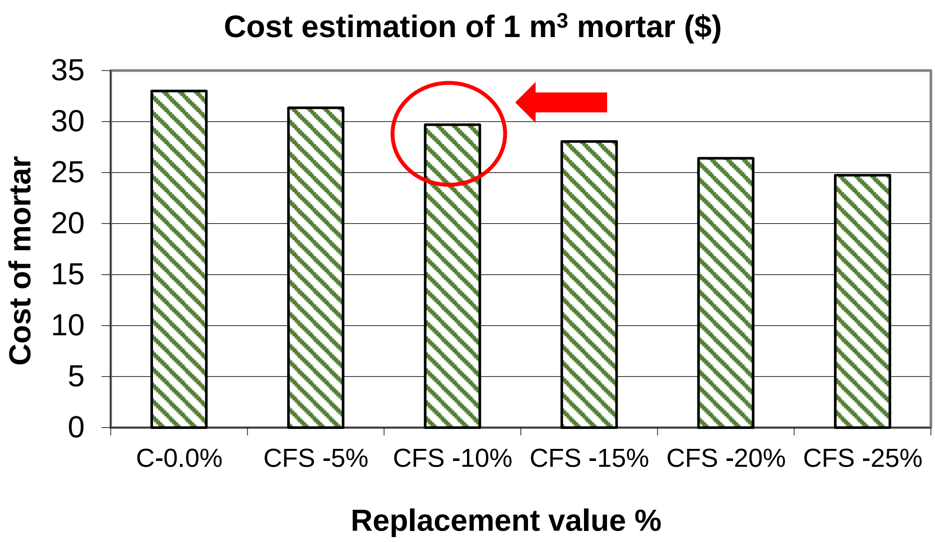

Figure 15. Cost of CFS mixtures (in $).

7. Conclusions

The physical and mechanical characteristics of the modified mortar were investigated. Based on the current experimental work's analysis, the following conclusions may be drawn:

1. A high replacement ratio requires the use of more water to obtain a particular consistency, and more water is required to maintain that consistency.
2. The compressive strength and unit weight relationship is proportional, which means that the greater the compressive strength, the lower the weight at the replacement ratio CFS-10%, and the lower the compressive strength, the lower the weight after the replacement ratio CFS-10%.
3. As water absorption increases, CFS replacement also increases; water absorption was higher in the CFS-25% mixture.
4. The replacement of CFS-10% as the optimal replacement ratio resulted in compressive strength values of 41.58 MPa at 7 days and 57.8 MPa at 28 days.
5. As may be observed from the findings of this research, the usage of CFS significantly improves the flexural strength by replacement ratios of 5%, 10%, and 15% of CFS; however, mechanical properties were lowered in the study after replacement ratios of 20%.
6. The surfaces of the CFS-5%, CFS-10%, and CFS-15% mixtures were rigid and non-porous, but the surfaces of the CFS-20% and CFS-25% mixtures were porous. This rigid surface may contribute to more strength, but the porous surface has less strength due to the dispersive structure.
7. Regarding the costs, the optimum replacement is 10%, which decreases the cost of 1 m^3 of mortar by 3.0% while increasing its strength.

Author Contributions: R.D.A.H.: Conceptualization; methodology; visualization; validation; writing—original draft preparation. M.H.-N.: writing—review, and editing. S.M.A.: review and editing. B.A.T.: Conceptualization; visualization; validation; writing—review, and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pavithra, C.; Arpan Maheshwari, A.A. Behaviour of concrete adding chicken feather as fibre with partial replacement of cement with Cashewnut shell powder. *Mater. Today Proc.* **2020**, *43*, 1173–1178. [CrossRef]
2. Pasupathy, K.; Ramakrishnan, S.; Sanjayan, J. Formulating eco-friendly geopolymer foam concrete by alkali-activation of ground brick waste. *J. Clean. Prod.* **2021**, *325*, 129180. [CrossRef]
3. Farming, C.I.W. Statistics: Broiler Chickens. 2013. Available online: www.ciwf.org (accessed on 6 October 2022).
4. Xin-gang, Z.; Yuan-feng, Z.; Yan-bin, L. The spillovers of foreign direct investment and the convergence of energy intensity. *J. Clean. Prod.* **2019**, *206*, 611–621. [CrossRef]
5. Karani, P.; Jewasikiewitz, S.M. Waste management and sustainable development in South Africa. *Environ. Dev. Sustain.* **2007**, *9*, 163–185. [CrossRef]
6. Sabapathy, K.A.; Gedupudi, S. On the influence of concrete-straw-plaster envelope thermal mass on the cooling and heating loads for different climatic zones of India. *J. Clean. Prod.* **2020**, *276*, 123117. [CrossRef]
7. Sudalaiyandi, G. Characterising the Cleaning Process of Chicken Feathers. Ph.D. Thesis, Waikato University, Hamilton, New Zealand, 2012.
8. Kock, J.W. Physical and Mechanical Properties of Chicken Feather Materials. Master's Thesis, Georgia Institute of Technology, Atlanta, GA, USA, 2006.
9. Gupta, A.; Kamarudin, N.B.; Kee, C.Y.G.; Yunus, R.B.M. *Extraction of Keratin Protein from Chicken Feather*; University of Malaysia Pahang: Pahang, Malaysia, 2011; pp. 2200–2209.
10. Frazer, L. Chicken Electronics: A Technology Plucked from Waste. *Environ. Health Perspect.* **2004**, *112*, A565–A567. [CrossRef]
11. Kondratyev, K.Y.; Galindo, I. Global climate change in the context of global ecodynamics. *Geofis. Int.* **1994**, *3*, 487–496. [CrossRef]
12. Ramesh, T.; Prakash, R.; Shukla, K.K. Life cycle energy analysis of buildings: Anoverview Energy Build. *CMB* **2010**, *42*, 1592–1600.
13. Raut, S.P.; Ralegaonkar, R.V.; Mandavgane, S.A. Development of sustainable construction material using industrial and agricultural solid waste: A review of waste-create bricks. *Constr. Build. Mater.* **2011**, *25*, 4037–4042. [CrossRef]
14. Gowsika, D.; Sarankokila, S.; Sargunan, K. Experimental Investigation of Egg Shell Powder as Partial Replacement with sand. *Int. J. Eng. Trends Technol.* **2014**, *14*, 65–68. [CrossRef]
15. Ako, T.A.; Onoduku, U.S.; Oke, S.A.; Essien, B.I.; Idris, F.N.; Umar, A.N.; Ahmed, A.A. Environmental Effects of Sand and Gravel Mining on Land and Soil in Luku, Minna Niger State, North Central Nigeria. *J. Geosci. Geomat.* **2014**, *2*, 42–49.
16. Sharma, A.K. Chicken feather as a substitute of fine aggregate in mortar. *Int. J. Adv. Eng. Sci. Res.* **2016**, *3*, 35–48.
17. Binici, H.; Aksogan, O.; Sevinc, A.H.; Cinpolat, E. Mechanical and radioactivity shielding performances of mortars made with cement, sand and eggshells. *Constr. Build. Mater.* **2015**, *93*, 1145–1150. [CrossRef]
18. Thirumurugan, V.; Raj, S.G.V.; Dheenadhayalan, K. Experimental Study on Strength of Mortar by Partial Replacement of Cement by Cashew Nut Shell Ash (CNSA) and Chicken Feather Fiber (CFF) as Fiber Reinforcement. *Int. J. Adv. Res. Ideas Innov. Technol.* **2018**, *3*, 110–119.
19. Barone, J.R. Polyethylene/Keratin Fiber Composites with Varying Polyethylene Crystalline. *Compos. Part A Appl. Sci. Manuf.* **2005**, *36*, 1518–1524. [CrossRef]
20. Barone, J.R.; Schmidt, W.F. Polyethylene Reinforced with Keratin Fibers Obtained from Chicken Feather. *Compos. Sci. Technol.* **2005**, *65*, 173–181. [CrossRef]
21. Hamoush, S.A.; El-Hawary, M.M. Feather Fiber Reinforced Concrete. *Mortar Int.* **2016**, *16*, 33–35.
22. Parkinson, G. Chementator: A Higher Use for Lowly Chicken Feathers? *Chem. Eng.* **2015**, *105*, 21.
23. Barone, S.W., Jr.; Liebner, C.F. Compounding and Molding Composites Reinforced Keratin Feather Fiber. *Compos. Sci. Technol.* **2005**, *65*, 683–692. [CrossRef]
24. Manikandan, J.; Subramanian, R.; Chinnadurai, G.; Buvaneswari, S.; Manikam, N.; Musthafa, A.M. Chicken Feather Powder as Corrosion Inhibitor for Aluminium in NaOH Solution. *Asian J. Chem.* **2015**, *27*, 1484–1488.
25. Belarmino, D.D.; Ladchumananandasivam, R.; Belarmino, L.D.; Pimentel, J.R.; da Rocha, B.G.; Galvão, A.O.; de Andrade, S.M.B. Physical and morphological structure of chicken feathers (keratin biofiber) in natural, chemically and thermally modified forms. *Mater. Sci. Appl.* **2012**, *3*, 887–893.
26. *Bs En 4550-3.41978*; British Standards Institution BSI: London, UK, 2020.
27. Abishek, K.; Karthiyan, N.M. Experimental Study on Strength of Concrete by Partially Replacement of Payment by Cashew Nut-Shell Ash (Cnsa) and Chicken Feather Fibre (Cff) as Fibre Reinforcement. *Int. J. All Res. Educ. Sci. Methods* **2021**, *9*, 238–242.
28. El-Hawary, M.M.; Hamoush, S.A. Strength of concrete reinforced withtreated feathers. *Constr. Build. Mater.* **2018**, *8*, 173–176. [CrossRef]
29. Lau, K.T.; Hung, P.Y.; Zhu, M.H.; Hui, D. Properties of natural fibre composites for structural engineering applications. *Compos. Part B* **2018**, *136*, 222–233. [CrossRef]
30. Merli, R.; Preziosi, M.; Acampora, A.; Lucchetti, M.C.; Petrucci, E. Recycled fibers in reinforced concrete: A systematic literature review. *J. Clean. Prod.* **2020**, *248*, 119207. [CrossRef]
31. Eziefula, U.G.; Ezeh, J.C.; Eziefula, B.I. Properties of seashell aggregate concrete: A review. *Constr. Build. Mater.* **2018**, *128*, 287–300. [CrossRef]
32. Noguchi, T.; Nemati, K.M. Relationship between compressive strength and modulus of elasticity of high-strength concrete. *J. Struct. Constr. Eng.* **2018**, *60*, 1–10.

33. Mrajji, O.; Wazna, M.E.; Boussoualem, Y.; Bouari, A.E.; Cherkaoui, O. Feather waste as a thermal insulation solution: Treatment, elaboration and characterization. *J. Ind. Text.* **2021**, *50*, 1674–1697. [CrossRef]
34. Coppola, B.; Courard, L.; Michel, F.; Incarnato, L.; Scarfato, P.; Di Maio, L. Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates. *Constr. Build. Mater.* **2018**, *170*, 200–206. [CrossRef]
35. Acda, M.N. Waste Chicken Feather as Reinforcement in Cement-Bonded Composites. *Philipp. J. Sci.* **2010**, *139*, 161–166.
36. Mendoza, R.C.; Grande, J.O.; Acda, M.N. Effect of Keratin Fibers on Setting and Hydration Characteristics of Portland Cement. *J. Nat. Fibers* **2021**, *18*, 1801–1808. [CrossRef]
37. Aranberri, I.; Montes, S.; Azcune, I.; Rekondo, A.; Grande, H.J. Fully Biodegradable Biocomposites with High Chicken Feather Content. *Polymers* **2017**, *9*, 593. [CrossRef]
38. Abdelsamie, K.; Agwa, I.S.; Tayeh, B.A.; Hafez, R.D.A. Improving the brittle behaviour of high-strength concrete using keratin and glass fibres. *Adv. Concr. Constr.* **2021**, *12*, 469–477.
39. Choudary, R.B.; Nehanth, R. Effects of fibre content on mechanical properties of chicken feather fibre/PP composites. *Mater. Today Proc.* **2019**, *18*, 303–309. [CrossRef]
40. Grzeszczyk, S.; Matuszek-Chmurowska, A.; Vejmelková, E.; Černý, R. Reactive powder concrete containing basalt fibers: Strength, abrasion and porosity. *Materials* **2020**, *13*, 2948. [CrossRef]
41. Degirmenci, N.; Yilmaz, A.; Cakir, O.A. Utilization of waste glass as sand replacement in cement mortar. *Indian J. Eng. Mater.* **2011**, *18*, 303–308.
42. Ismail, Z.Z.; Al-Hashmi, E.A. Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Manag.* **2009**, *29*, 655–659. [CrossRef]
43. McGauran, T.; Harris, M.; Dunne, N.; Smyth, B.M.; Cunningham, E. Development and optimization of extruded bio-based polymers from poultry feathers. *Eur. Polym. J.* **2021**, *158*, 110678. [CrossRef]
44. Rishi, A.M.; Kandlikar, S.G.; Gupta, A. Improved wettability of graphene nanoplatelets (GNP)/copper porous coatings for dramatic improvements in pool boiling heat transfer. *Int. J. Heat Mass Transf.* **2019**, *132*, 462–472. [CrossRef]
45. Tesfaye, T.; Sithole, B.; Ramjugernath, D.; Chunilall, V. Valorisation of chicken feathers: Characterisation of chemical properties. *Waste Manag.* **2017**, *68*, 626–635. [CrossRef]
46. Islam, M.R.; Beg, M.D.H.; Jamari, S.S. Characterization of multiwalled carbon nanotube filled, palm-oil-based polyalkyds: Effects of loading and in situ reaction. *J. Appl. Polym. Sci.* **2016**, *133*, 42934. [CrossRef]
47. Pour, Z.S.; Ghaemy, M. Polymer grafted graphene oxide: For improved dispersion in epoxy resin and enhancement of mechanical properties of nanocomposite. *Compos. Sci. Technol.* **2016**, *136*, 145–157. [CrossRef]
48. Zhang, T.; Dieckmann, E.; Song, S.; Xie, J.; Yu, Z.; Cheeseman, C. Properties of magnesium silicate hydrate (M-S-H) cement mortars containing chicken feather fibres. *Constr. Build. Mater.* **2018**, *180*, 692–697. [CrossRef]
49. Dalhat, M.A.; Osman, S.A.; Alhuraish, A.A.A.; Almarshad, F.K.; Qarwan, S.A.; Adesina, A.Y. Chicken Feather fiber modified hot mix asphalt concrete: Rutting performance, durability, mechanical and volumetric properties. *Constr. Build. Mater.* **2020**, *239*, 117849. [CrossRef]
50. Araya-Letelier, G.; Gonzalez-Calderon, H.; Kunze, S.; Burbano-Garcia, C.; Reidel, U.; Sandoval, C.; Bas, F. Bas Waste-based natural fiber reinforcement of adobe mixtures: Physical, mechanical, damage and durability performance assessment. *J. Clean. Prod.* **2020**, *273*, 122806. [CrossRef]
51. Poole, A.J.; Church, J.S.; Huson, M.G. Environmentally sustainable fibers from regenerated protein. *Biomacromolecules* **2009**, *10*, 1–8. [CrossRef]
52. Acda, M.N. Sustainable use of waste chicken feather for durable and low-cost building materials for tropical climates. *Sustain. Agric. Technol. Plan. Manag.* **2010**, *2448*, 353–366.