The Impact of Recycled Material Reinforcement on the Performance of Mortars

Wahaj Alhabib
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
48579@aum.edu.kw

Jood Alhawal
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
50167@aum.edu.kw

Batlah AlRashidi
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
57669@aum.edu.kw

Shaikha AlAbdulqader
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
57004@aum.edu.kw

Zinab AlSayegh
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
52333@aum.edu.kw

Enea Mustafaraj
College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
enea.mustafaraj@aum.edu.kw (corresponding author)

Received: 29 July 2024 | Revised: 20 August 2024 | Accepted: 24 August 2024

 DOI: https://doi.org/10.48084/etasr.8556

ABSTRACT

This study investigates the use of recycled fibers as reinforcement in structural mortar to enhance its mechanical and physical properties. Polypropylene from onion bags, cotton from jeans, mesh fibers from date palms, and steel wool from dish sponges of various concentrations were tested as recycled materials. Experimental tests were performed on 63 mortar prisms, each measuring 40 mm × 40 mm × 160 mm. Fiber concentrations varied for each material type. Reinforced fiber mortar improvement was compared to control specimens in terms of flexural and compressive strength and failure mode. The determined optimal percentages were 0.2% polypropylene, 1.6% jeans, 2% date palm mesh, and 1% steel wool fibers. SEM analysis was also performed to explore the microstructure and bonding ability of the fibers within the mortar matrix.

Keywords-recycled fibers; sustainability; fiber-reinforced mortar; flexural strength; compressive strength; SEM analysis

I. INTRODUCTION

The construction sector is increasingly adopting sustainable practices, leading to a renewed interest in the use of recycled materials. Cement or lime mortar, which is the binding agent in structural masonry, is known to be the weakest link in the load-bearing system. This research explores the addition of recycled fibers in mortar to improve mechanical properties and create an environmentally friendly mortar mix suitable for modern construction methods. Integration of these sustainable materials in construction methods has been examined regarding their practical implications and performance outcomes. Authors in [1] found that incorporating steel wool fibers at a 0.75% volume fraction enhanced the flexural strength by 62.38% and the toughness of mortar slabs [1]. Authors in [2] showed that 4% steel fibers could enhance post-fire recovery by improving compressive strength. Authors in [3] found that polypropylene fibers enhanced the bond strength of polymer-modified cement mortar at 0.75% volume fractions. Similarly, authors in [4] found that polypropylene fiber-stabilized loess improved strength and resistance to deterioration when the fiber content was 0.5% [4]. Regarding cotton fibers, authors in [5] discovered that recycled cotton fibers improved flexural strength but reduced workability and compressive strength, with the optimal balance found at 0.8% cotton fiber addition. Authors in [6] found that adding 5% textile fiber was the most effective, as it reduced density without compromising compressive strength. Authors in [7] found that mesh date palm fibers could improve mortar's bending and compression strength by 50%. Further, authors in [8, 9] investigated mortar reinforced with date palm fibers and which improved ductility and weight performance and enhanced flexural strength and sulfate resistance. Some examples from the Middle East involve the usage of date palm fibers in concrete [10-13]. The results showed improved density, ultrasonic pulse velocity, and water permeability.

Kuwait is implementing sustainable building techniques, including incorporating recycled materials into mortar, to support economic growth and preserve its natural legacy. This aligns with the country's Vision of 2035 [14] in terms of waste management, the promotion of a circular economy, and the establishment of Kuwait as a regional leader in sustainable development. The project aims to investigate the use of recycled fiber materials as mortar reinforcement, supporting Kuwait's long-term development goals and promoting environmental sustainability. Further, it aims to demonstrate the viability and efficiency of using recycled materials in construction processes, ensuring the sustainability of the materials used in the construction process. Recycling of gypsum wastes [15], as well as using micro steel fibers [16] in mortar mixes, has proven to achieve good results.

This study seeks to evaluate the impact of four different fiber types on three key properties of mortar: water absorption, compressive strength, and flexural strength. The innovation of this research is highlighted by the use of varying fiber percentages and the application of Scanning Electron Microscopy (SEM) analysis to investigate the microstructure and bonding characteristics of the fibers within the mortar matrix.

II. MATERIALS AND METHODS

A. Materials

The mortar mixes were prepared using Ordinary Portland Cement (OPC), fine aggregate sand, and water. Materials were chosen for their availability, compliance with standards, and ability to enhance mortar's mechanical properties.

B. Cement, Sand, and Water

Mortar made with OPC Type 1 was selected in compliance with ASTM C 150 [17]. OPC has a lower resistance to shrinkage and chemical attacks than other types of concrete, it has a fast-setting time, and is suitable for early removal of formwork. The mortar mix sand was thoroughly washed and met ASTM C33 specifications [18]. Fine-grade sand ensures optimal workability, strength, and aesthetic appearance of the mortar mix. It contributes to a more cohesive and durable mortar due to its uniform grain size distribution, which minimizes voids within the mortar. The water used in the construction met quality standards, making it free of harmful impurities that could adversely affect the mortar's ability to hydrate and hold together.

C. Fibers Used

- Date Palm (DP) Fibers: DP were extracted from date palm trunks, air-dried for 48 h, and cut to 10 mm to enhance strength and durability for mortar application. Because of their high tensile strength and biodegradable nature, they can improve the flexural strength and mortar sustainability [19].
- Polypropylene (PP) Fibers: Recycled onion bags were used to generate PP fibers that were cut to a uniform length of 10 mm. These fibers' durability and moisture resistance enhance a mortar's structural integrity [20-21].
- Cotton (C) / Jean (J) Fibers: Derived from industrial and household waste, these fibers were manually cut to 10 mm length, highlighting the need for more efficient cutting methods such as machine shredders to ensure integrity and uniformity for construction uses. Their high tensile strength and biodegradability improve crack resistance and energy dissipation in mortar.
- Steel Wool (SW) Fibers: SW fibers were processed and cut to 10 mm in length from dish sponges and household waste. This inclusion significantly improves the mortar's durability and load distribution.

The fibers used as reinforcing material for the mortar specimen are shown in Figure 1.

Table I summarizes the physical and engineering characteristics of the fibers used in this study. Repurposing fibers to a specific size (Figure 1), appears to have minimal effect on their microstructure. To avoid adverse effects on the fibers' properties, repurposing fibers should avoid harsh chemical treatments [4].

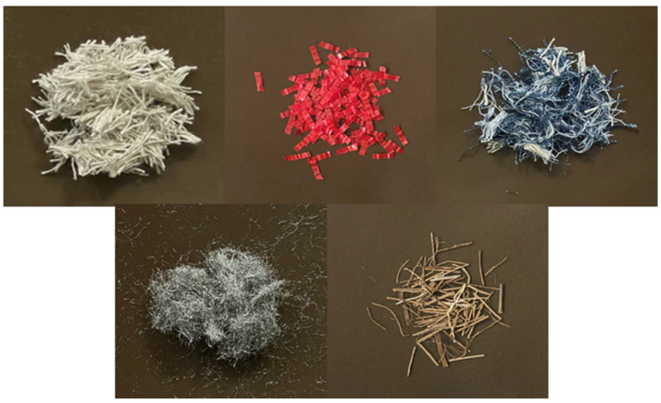

Fig. 1. Cotton, polypropylene, jeans, steel wool and date palm fibers.

TABLE I. FIBER PHYSICAL PROPERTIES AND ENGINEERING CHARACTERISTICS

Fiber type	Physical properties	Engineering characteristics
DP mesh fibers	Lightweight, high tensile strength, and resistant to environmental degradation.	Enhances energy absorption and flexural strength.
C (J) fibers	Abrasion resistance, high tensile strength, and biodegradability.	Enhances crack resistance, increases tensile strength, and dissipates energy efficiently under load.
SW fibers	Durable, high tensile strength, and abrasion resistance.	Exceptional crack resistance, improved load distribution, and improved thermal and electrical conductivity.
PP fibers	Lightweight, durable, chemically resistant, moisture-resistant, rot-resistant, and moisture-proof.	A higher tensile strength, improved crack control, and better resistance to cyclic loading.

D. Mix Design and Specimen Preparation

Figure 2 shows the specimen preparation and testing procedure. The mix design of mortar constituents was the same for all specimens. A water-cement ratio of 0.5 was used, along with a cement-sand ratio of 1:3. The mixture design for casting the samples and fiber-type usage rates are shown in Table II. Among the fibers included in the mortar mixture, four main types were used, each at three different percentages by composite volume: PP at 0.1%, 0.2%, and 0.3%; SW fibers at 0.75%, 1%, and 1.5%; DP at 1%, 2%, and 3%; and C fibers at 2%, 3%, and 5% and J fibers at 1.6% (Figure 3). For comparison, the fiber percentage for one type was kept consistent with values reported in the literature, while two additional percentages were introduced to examine how varying fiber content influences the mortar's properties.

The experimental program consisted of casting a total of 63 mortar samples of 40 mm × 40 mm × 160 mm at the Construction Materials Laboratory of the American University of the Middle East. The specimens were cured for 28 days. After curing, water absorption and flexural and compressive strengths as per BS EN 1015-11[22] were determined.

The samples are named according to the following convention: "M" represents mortar, followed by the abbreviation of the fibers and the percentage of each mix. For example, MDP3 denotes a mortar sample reinforced with a 3% concentration of date palm fibers.

Fig. 2. Specimen preparation and testing procedure.

Fig. 3. Mortar specimens ready for testing.

TABLE II. MIX PROPORTIONS

Specimen	Mortar Mix Design			
	Cement (g)	Water (g)	Sand (g)	Fiber Mass (g)
Control	180	90	274	-
MPP0.1	180	90	274	0.23
MPP0.2	180	90	274	0.46
MPP0.3	180	90	274	0.69
MSW0.75	180	90	274	0.96
MSW1	180	90	274	1.28
MSW1.5	180	90	274	1.92
MCJ2	180	90	274	7.78
MCJ3	180	90	274	11.67
MCJ5	180	90	274	19.46
MCJ1.6	180	90	274	9.34
MDP1	180	90	274	1.51
MDP2	180	90	274	3.02
MDP3	180	90	274	4.53

III. RESULTS AND DISCUSSION

A. *Water Absorption*

The water absorption results are depicted in Figure 4. The water absorption of the control specimens was 12.9%. The addition of 0.1% PP fibers in the mix resulted in a 10.84% water absorption rate, indicating that the matrix density remained relatively constant. A slight decrease to 10.60% in the 0.2% mix indicated improved compactness and internal cohesion, whereas the 0.3% mix demonstrated increased absorption of 12.47%, most likely due to the increased porosity. The ideal fiber content for PP fibers is 0.2%, which results in the lowest water absorption.

When SW fibers were added at a rate of 0.75%, the water absorption decreased to 11.88%, indicating a possible reduction in porosity. At 1% fiber content, the water absorption rate further decreased to 11.67%, enhancing structural compactness. On the other hand, 1.5% fiber content raised the water absorption rate to 13.27%, marginally higher than the control, presumably as a result of increased porosity or matrix structure disruption. For steel wool fibers, 1% is the ideal fiber concentration since it yields the lowest water absorption rate.

Analyzing DP mesh fibers revealed that the water absorption rose to 14.52% with the addition of 1% fiber, indicating an increased porosity. The water absorption declined to 13.44% at 2% fiber content, indicating that the fibers filled in gaps and strengthened the structure. Nevertheless, the absorption rate rose to 13.7% at 3% fiber content, indicating a critical threshold where structural advantages are maximized and porosity is minimized. The ideal fiber content for date palm mesh fibers is 2%, which has a lower water absorption rate than other concentrations.

The water absorption of C fibers was 12.9%. Increased C fiber content increases porosity and water absorption, as demonstrated by the absorption rates of 16.14%, 17.25%, and 19.53% obtained by adding 2%, 3%, and 5% of cotton fibers, respectively. Conversely, a more moderate increase in porosity (i.e. 15.43% absorption) was obtained by adding 1.6% J fibers, suggesting that C fibers have a more vivid effect at similar or higher concentrations. The optimal fiber content for C fibers is not precisely defined, as all tested concentrations considerably increased water absorption. However, J fibers at 1.6% exhibited a mild rise and might be deemed comparatively optimal.

As expected, the water absorption results are inversely related to the mechanical properties discussed below.

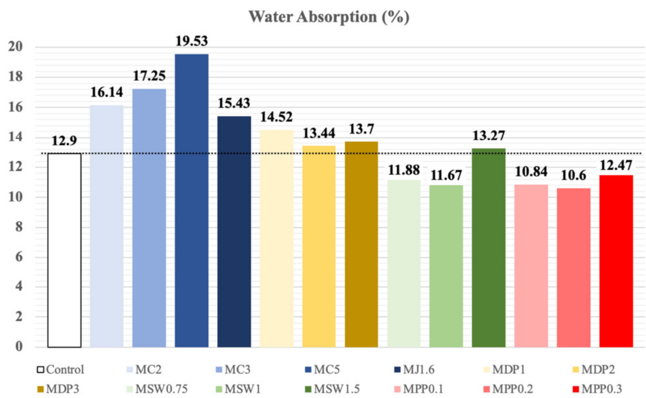

Fig. 4. Water absorption of mortar for various types of fibers.

B. *Flexural Strength*

The 28-day flexural strength results are summarized in Figure 5. The results were compared to those of the control mix.

The flexural strength of PP fibers in the control specimens was 4.45 MPa. Flexural strength was 2.02% higher with 0.1% PP fiber when compared to the control specimen. This shows that the bending resistance of the mortar can be increased by adding a small amount of fibers. A slight gain of 1.57% above the control is seen in strength when the fiber content is raised to 0.2%, falling to 4.52 MPa. Only a 0.67% improvement in strength occurs with 0.3% addition, indicating that an excessive amount of fiber may cause the cement matrix to become disrupted. For flexural strength, a 0.1% PP fiber content can be considered ideal.

Adding 0.75% SW fibers yields an average flexural strength of 5.09 MPa with an increase of 14.38% from control's 4.45 MPa. This improvement suggests that the mortar's resistance to bending can be greatly increased by adding a moderate amount of SW fibers. The flexural strength rises to

5.28 MPa—an 18.65% increase over control—when the fiber content is increased to 1.00%. Higher SW concentrations seem to keep enhancing the structural integrity of mortar. However, the flexural strength unexpectedly drops to 2.99 MPa, a considerable loss of 32.81%, when the concentration exceeds 1.50%. In this instance, the cohesiveness within the mortar matrix may have been compromised by clumping or uneven fiber distribution, leading to such a sharp decline. Therefore, the optimal flexural strength is achieved at 1.00% SW fiber concentration.

Strength drops by 28.31% to 3.19 MPa at a 1% DP mesh fiber concentration, suggesting that very little fiber addition does not improve structural integrity. Strength rises to 4.64 MPa, 4.27% greater than control, when the fiber concentration is increased to 2%, suggesting that the fiber-matrix interaction is at its best. When the concentration was raised to 3%, the strength dropped by 17.08% to 3.69 MPa, indicating that fiber oversaturation has a detrimental effect on mortar cohesiveness. The results of this study highlight the significance of striking a balance between cohesive properties and fiber reinforcement, as DP mesh fibers have a substantial impact on mortar flexural strength. A DP mesh fiber concentration of 2% yields the best flexural strength results.

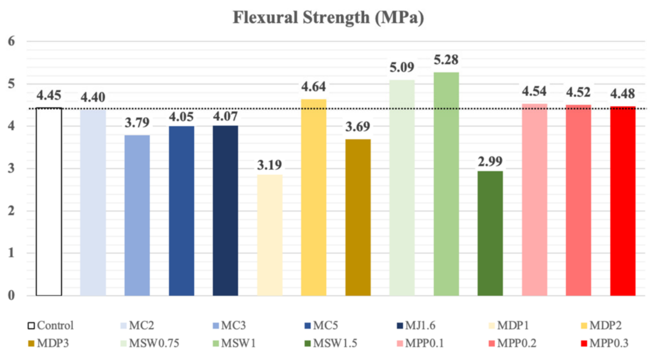

Fig. 5. Flexural strength results of mortar specimens.

The strength dropped to 4.07 MPa, an 8.54% decrease after 1.6% J fibers were added. Because of the uneven fiber distribution or potential interference with cement matrix bonding, J fiber integration at this concentration may have a bad influence on the structural cohesion of the mortar. Flexural strength for specimens reinforced with C fibers was found to vary between concentrations. An ideal fiber-matrix interaction is indicated by a 1.12% drop in flexural strength at 2% fiber concentration, which implies minimal effects on mortar structural integrity. On the other hand, strength was considerably decreased by 14.83% for 3% fiber content. The strength dropped to 4.05 MPa at a 5% concentration, an 8.99% decrease from control. This suggests that there is a complicated link between fiber volume and mortar cohesion.

Figure 6 demonstrates the failure mode of a C fiber-reinforced specimen. In this case, a 2% cotton fiber percentage finds a balance without materially compromising structural integrity The fibers helped bridge cracks and distributed the stress more evenly across the mortar matrix.

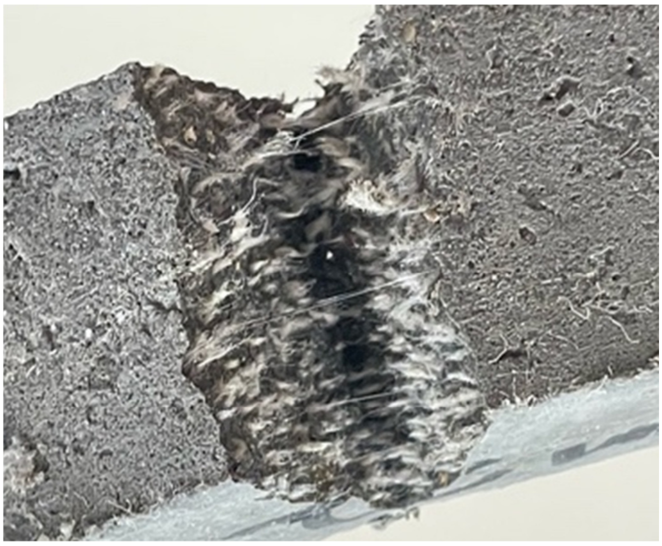

Fig. 6. C fibers within mortar after flexural test.

C. Compressive Strength

The 28-day compressive strength values of the specimens with varying fiber contents and types are shown in Figure 7. The outcomes were compared with the control specimen results. The control specimens' compressive strength was 23.79 MPa.

Adding 0.1% PP fiber resulted in a modest increase to 24.01 MPa, up 0.93%. With 0.2% fiber, there was a more noticeable improvement—the strength rose to 24.72 MPa, a 3.91% increase—which was attributable to matrix reinforcement and ideal fiber dispersion. With 0.3% fiber content, the compressive strength increased to 27.37 MPa, a significant 15.05% improvement, indicating good fiber-matrix bonding and efficient load transfer. For compressive strength, a 0.3% PP fiber percentage is ideal.

For SW fibers, adding 0.75% enhanced compressive strength to 26.62 MPa, an 11.91% increase over control. With 1% fiber, the compressive strength peaked at 33.40 MPa, a 40.35% improvement. This shows that the fibers and matrix interact well for effective load transmission and stress distribution. However, at 1.50% fiber concentration, compressive strength declined considerably to 16.01 MPa, a 32.72% loss, most likely because of a dense fiber network that inhibited appropriate cement hydration and matrix formation. Therefore, the optimal compressive strength is achieved with a SW fiber content of 1%.

When 1% DP fiber was added, the strength dropped to 14.31 MPa, a 39.8% decrease, suggesting detrimental effects on structural integrity. Strength increased by 5.67% at 2% fiber content, indicating more excellent fiber distribution and increased strength. However, a minor decline to 22.74 MPa, or a 4.42% loss, was seen when the fiber concentration was increased to 3%, suggesting a threshold beyond which more fibers degrade performance. A 2% fiber percentage yields the best compressive strength for DP mesh fibers.

When 2% C fibers were added, the strength dropped by 11.56% to 21.04 MPa. The strength further dropped by 16.41% to 19.88 MPa with 3% C fiber content. At 5% fiber content, a considerable decrease was seen, with the strength decreasing by 369.29% to 15.01 MPa. On the other hand, the compressive strength improved by 9.41% to 26.03 MPa with the addition of 1.6% J fibers.

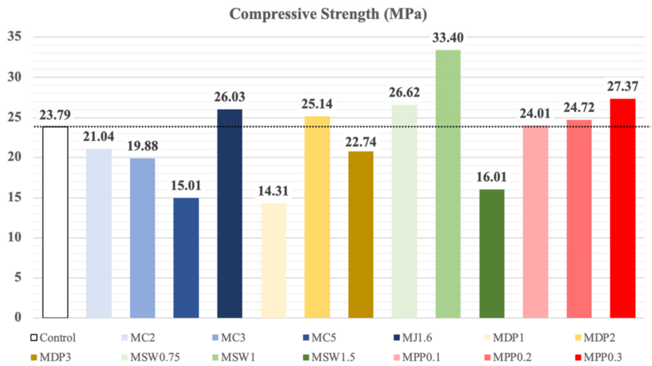

Fig. 7. Compressive strength results of mortar specimens.

D. Scanning Electron Microscopy (SEM) analysis

SEM analysis revealed details about the microstructure and bonding ability of the fibers within the mortar matrix. C fibers at a magnification of 40X can be seen in Figure 8, which shows a fibrous structure with comparatively smooth, elongated strands. The fibers are entangled in the mortar, suggesting that the matrix has been well-dispersed. However, some regions with pull-out gaps indicate possible partial fiber detachment from the matrix. These gaps can serve as locations for crack initiation. This microstructural configuration probably plays a factor in the cotton fibers' ability to improve the mortar's mechanical properties, especially the ductility.

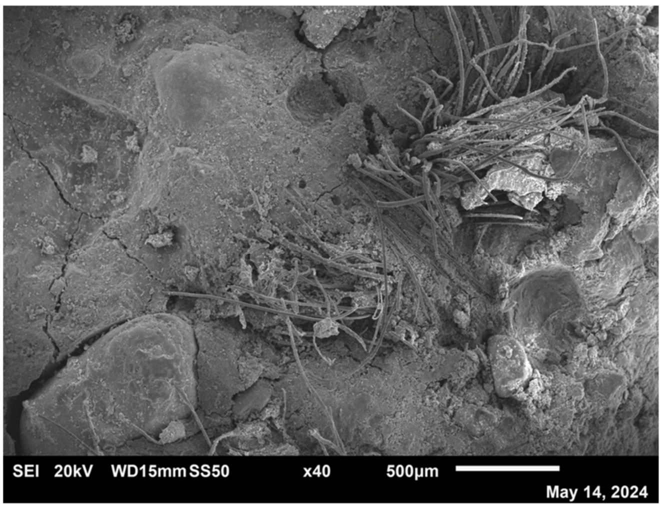

Fig. 8. SEM image of C fibers in mortar matrix

Figure 9 shows the SEM analysis of DP fiber cement, revealing a coarse, textured surface that helps mechanical interlocking. This characteristic can increase flexural strength by preventing pull-out and evenly dispersing loads. The fiber interacts well with the mortar mix, creating an adequate bonding.

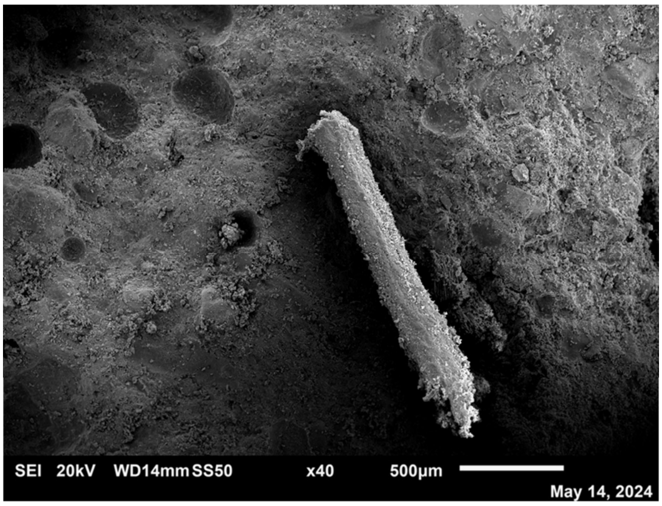

Fig. 9. SEM image of DP fibers in mortar matrix.

The SEM image of the SW fibers in Figure 10 shows a network of thin metallic strands with a high level of surface roughness. These fibers are tightly incorporated in the mortar matrix, resulting in a complex reinforcing structure. The steel fibers and the mortar matrix are in close contact and are mechanically interlocked, ensuring good load transfer and stress distribution. This microstructural characteristic emphasizes how the SW fibers considerably improve the structural integrity of the mortar.

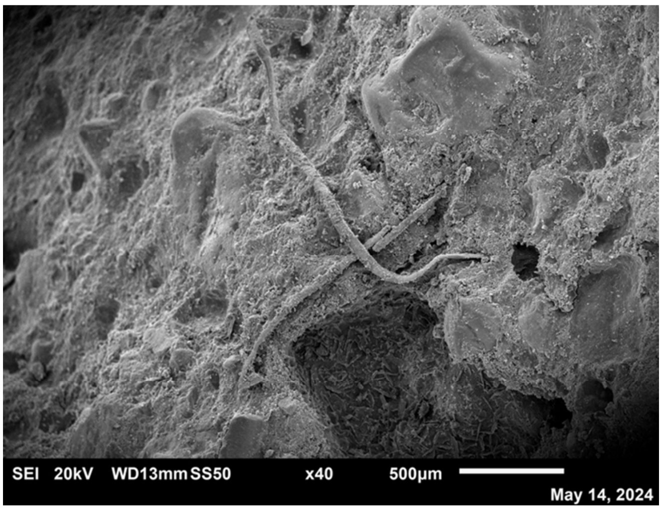

Fig. 10. SEM image of SW fibers in the mortar matrix.

The SEM image in Figure 11 reveals that the PP fibers appear as smooth strands. The flat surface of these fibers suggests minimal mechanical interlocking, however, their chemical compatibility with the cement matrix likely ensures adequate bonding. The matrix effectively surrounds the fibers, reducing the overall porosity of the mortar. The superior dispersion and confinement of the fibers contribute to the observed improvements in flexural strength and water absorption properties by filling cracks and increasing matrix density. Consequently, the PP fibers play a crucial role in enhancing the overall performance and durability of the mortar.

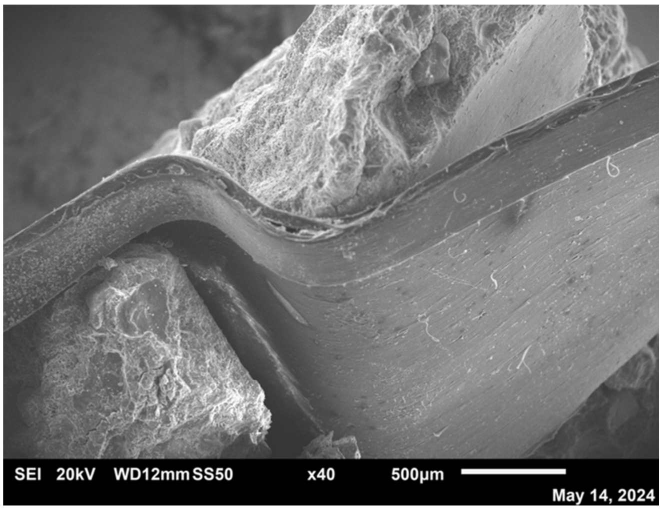

Fig. 11. SEM image of PP fibers in mortar matrix.

IV. CONCLUSION

This study aimed to analyze the impact of the addition of recycled fiber materials on the mechanical and physical properties of structural mortar. Various materials, including polypropylene from onion bags, cotton from clothes, date palm mesh, and steel wool from dish sponges, were tested for their impact on mortar properties. From each three different fiber contents, the most optimal fiber percentages that provided the best results were 0.2% for polypropylene fibers, 1% for steel wool fibers, 1.6% for jeans fibers, and 2% for date palm fibers.

The following conclusions can be drawn:

- The inclusion of polypropylene fibers in the mortar mix enhances its compactness and reduces water absorption to 10.60%.
- Steel wool fibers, when used at a 1% content, demonstrated the best mechanical performance, with an 18.65% increase in flexural strength and a 40.35% increase in compressive strength.
- Adding 2% date palm fibers led to a 4.27% improvement in flexural strength and a 5.67% improvement in compressive strength.
- While cotton fibers did not significantly enhance flexural or compressive strength, they improved the ductility and overall integrity of the mortar specimens.
- Each fiber material contributes differently, and increasing fiber content does not guarantee improvements in mechanical properties.
- Using recycled fibers in mortar is highly advantageous, offering a sustainable method to reduce waste while enhancing structural strength.

Further research on the durability and long-term performance of fibers in mortar is recommended.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Mohammad F. Abdulsalam for his invaluable assistance and to the Kuwait Institute for Scientific Research for providing the necessary facilities for the SEM analysis.

REFERENCES

[1] S. O. Franklin and K. S. Mronga, "Comparative study of mechanical properties of steel wool and polypropylene fibre reinforced cement mortar composites," *International Research Journal of Engineering and Technology*, vol. 8, no. 12, pp. 1609–1614, 2021.

[2] M. M. Sazzad, N. Sudipta, and S. Poly, "Strength Behavior of Cement Mortar Reinforced with Steel Fibers at Elevated Temperature," *Journal of Civil and Construction Engineering*, vol. 6, no. 1, pp. 19–26, Jan. 2020, https://doi.org/10.5281/zenodo.3625683.

[3] P. I. Abdulrahman and D. K. Bzeni, "Bond strength evaluation of polymer modified cement mortar incorporated with polypropylene fibers," *Case Studies in Construction Materials*, vol. 17, Dec. 2022, Art. no. e01387, https://doi.org/10.1016/j.cscm.2022.e01387.

[4] H. Wang, W. Ni, and K. Yuan, "Mechanical properties, microstructural evolution, and environmental impacts of recycled polypropylene fiber stabilized loess," *Construction and Building Materials*, vol. 400, Oct. 2023, Art. no. 132850, https://doi.org/10.1016/j.conbuildmat.2023.132850.

[5] W. Tang, R. Monaghan, and U. Sajjad, "Investigation of Physical and Mechanical Properties of Cement Mortar Incorporating Waste Cotton Fibres," *Sustainability*, vol. 15, no. 11, Jan. 2023, Art. no. 8779, https://doi.org/10.3390/su15118779.

[6] U. Gunathilaka, C. Jayathilaka, and H. M. C. Somarathna, "Feasibility of Cement Mortar System with Textile Waste," in *International Conference on Engineering - 2022*, Aug. 2022.

[7] H. Khelifa *et al.*, "Mechanical characterization of mortar reinforced by date palm mesh fibers: Experimental and statistical analysis," *Construction and Building Materials*, vol. 300, Sep. 2021, Art. no. 124067, https://doi.org/10.1016/j.conbuildmat.2021.124067.

[8] S. Vantadori, A. Carpinteri, and A. Zanichelli, "Lightweight construction materials: Mortar reinforced with date-palm mesh fibres," *Theoretical and Applied Fracture Mechanics*, vol. 100, pp. 39–45, Apr. 2019, https://doi.org/10.1016/j.tafmec.2018.12.011.

[9] N. G. Ozerkan, B. Ahsan, S. Mansour, and S. R. Iyengar, "Mechanical performance and durability of treated palm fiber reinforced mortars," *International Journal of Sustainable Built Environment*, vol. 2, no. 2, pp. 131–142, Dec. 2013, https://doi.org/10.1016/j.ijsbe.2014.04.002.

[10] F. Althoey *et al.*, "Behavior of Concrete Reinforced with Date Palm Fibers," *Materials*, vol. 15, no. 22, Jan. 2022, Art. no. 7923, https://doi.org/10.3390/ma15227923.

[11] M. Sh. Al-Otaibi, O. Y. Alothman, M. M. Alrashed, A. Anis, J. Naveen, and M. Jawaid, "Characterization of Date Palm Fiber-Reinforced Different Polypropylene Matrices," *Polymers*, vol. 12, no. 3, Mar. 2020, Art. no. 597, https://doi.org/10.3390/polym12030597.

[12] Y. E. Ibrahim, M. Adamu, M. L. Marouf, O. S. Ahmed, Q. A. Drmosh, and M. A. Malik, "Mechanical Performance of Date-Palm-Fiber-Reinforced Concrete Containing Silica Fume," *Buildings*, vol. 12, no. 10, Oct. 2022, Art. no. 1642, https://doi.org/10.3390/buildings12101642.

[13] A. Kriker, G. Debicki, A. Bali, M. M. Khenfer, and M. Chabannet, "Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate," *Cement and Concrete Composites*, vol. 27, no. 5, pp. 554–564, May 2005, https://doi.org/10.1016/j.cemconcomp.2004.09.015.

[14] " Kuwait Vision 2035 "New Kuwait." MOFA, https://www.mofa.gov.kw/en/pages/kuwait-vision-2035.

[15] E. M. Ragab, T. M. Awwad, and N. Becheikh, "Thermal and Mechanical Properties Enhancement of Cement Mortar using Phosphogypsum Waste: Experimental and Modeling Study," *Engineering, Technology & Applied Science Research*, vol. 14, no. 2, pp. 13153–13159, Apr. 2024, https://doi.org/10.48084/etasr.6875.

[16] M. S. Amouri and N. M. Fawzi, "The Mechanical Properties of Fly Ash and Slag Geopolymer Mortar with Micro Steel Fibers," *Engineering, Technology & Applied Science Research*, vol. 12, no. 2, pp. 8463–8466, Apr. 2022, https://doi.org/10.48084/etasr.4855.

[17] *ASTM C150/C150M-22(2022), Standard Specification for Portland Cement*. West Conshohocken, PA, USA: ASTM International, 2022.

[18] *ASTM C33/C33M-18(2018), Standard Specification For Concrete Aggregates*. West Conshohocken, PA, USA: ASTM International, 2018.

[19] L. Kohan, L. S. Coelho, J. Baruque-Ramos, and H. Savastano Junior, "Cellulosic Fabric-Reinforced Cementitious Matrix (FRCM): Ligaments, Treatments, and Employment," *Materials Circular Economy*, vol. 4, no. 1, Jan. 2022, Art. no. 8, https://doi.org/10.1007/s42824-022-00052-8.

[20] N. Bahlouli *et al.*, "Recycling effects on the rheological and thermomechanical properties of polypropylene-based composites," *Materials & Design*, vol. 33, pp. 451–458, Jan. 2012, https://doi.org/10.1016/j.matdes.2011.04.049.

[21] T. Thwe Win, P. Jongvivatsakul, T. Jirawattanasomkul, L. Prasittisopin, and S. Likitlersuang, "Use of polypropylene fibers extracted from recycled surgical face masks in cement mortar," *Construction and Building Materials*, vol. 391, Aug. 2023, Art. no. 131845, https://doi.org/10.1016/j.conbuildmat.2023.131845.

[22] *BS EN 1015-11(2019), Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar*. London, UK: British Standards Institution, 2019.