Development of Sustainable Construction Materials Out of Paper Waste towards Green Buildings

Undergraduate Research Competition

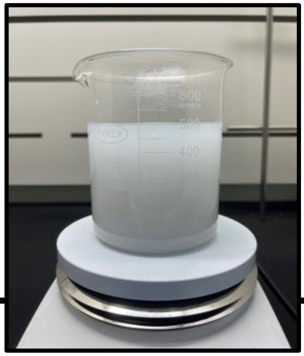
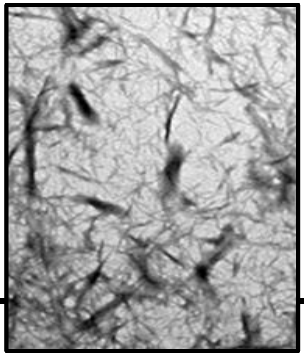
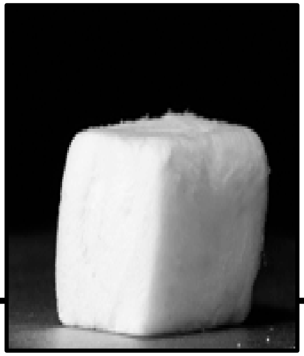
Abu Dhabi University

Saydah Ahmed and **Aya Yassine**

Dr. Hatem Abushammala **|** **Abu Dhabi University**
Mr. Mohanad Ibrahim, Mr. Mika Viertola, Mr. Rabih El Assadi | **Ittihad Paper Mill LCC**

Thursday, 23.05.2024



Introduction

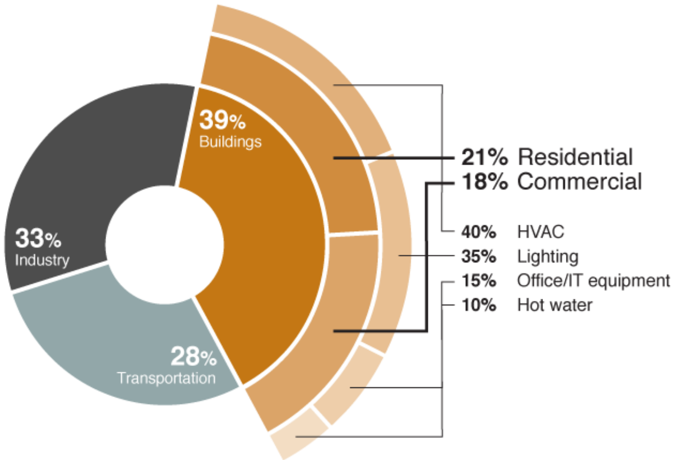
- Paper waste is the most abundant component of municipal solid waste, with a percentage of ca. 30% (Zhou et al., 2015).
- It is also generated as paper reject in papermills during the papermaking process (Bajpai et al., 2015).
- Paper waste is viewed as a resource as per the circular economy concept (Shakir et al., 2013).
- It can be utilized by breaking it down into its physical and chemical structures to create new products (Zhou et al., 2015).

Ittihad Paper Mill LCC

- Ittihad Paper Mill (IPM), is the largest producer of printing and writing paper in the MENA region.
- IPM's products are in compliance with global environmental standards, with pulp being sourced only from certified sustainable forests.
- This is in line with ADU's vision regarding environmental sustainability and resource management.
- In this project, we aim to utilize a major paper reject stream (Broke Screen Reject**,** 43 m^3/day) from IPM's papermaking process.

Green Buildings

- Buildings are responsible for a significant amount of energy, electricity, and resource consumption (Gholipour et al., 2022).
- Lowering buildings' energy use is essential for accomplishing the SDGs (Liu et al., 2022).
- A "green building" minimizes or prevents adverse effects on the climate and environment (Gholipour et al., 2022).
- Energy and material efficiency are two major aspects of green buildings (Haile et al., 2021).
- Insulation materials, crucial in UAE and GCC, impact energy consumption (Haile et al., 2021).



(Pichtel, 2014)

USA (2015): 39%
EU (2014): 38%
UAE (2013): 60%

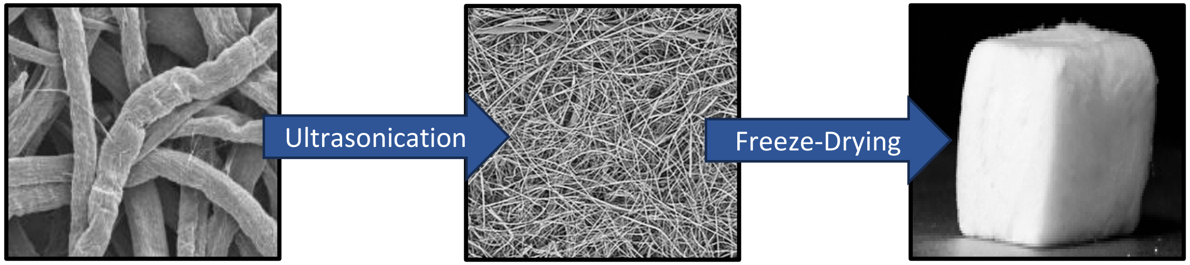
Construction Materials Out of Paper Waste

Project Goal

Overall Goal: Convert paper waste into a sustainable wall insulation material with low thermal conductivity for green buildings

Sub Goal I: Convert paper waste to cellulose nanofibrils (CNFs) using ultrasonication combined with acid pretreatment

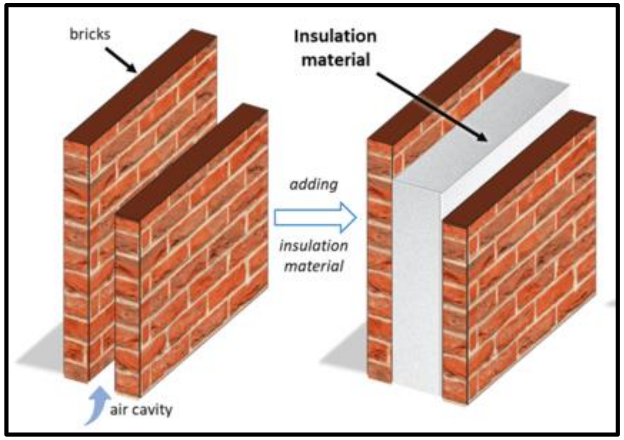
Sub Goal II: Convert the CNFs to an insulation foam with low thermal conductivity using freeze-drying



Paper Waste - Cellulose Fibers

Cellulose Nanofibrils (CNFs)

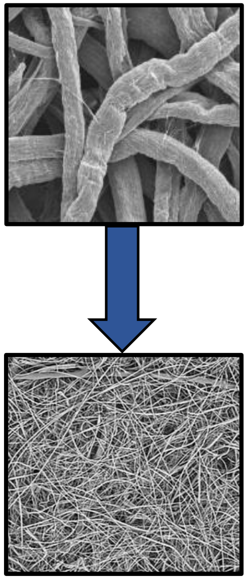
Insulation Foam with Low Thermal Conductivity



Cellulose nanofibers (CNFs)

- Cellulose, the most abundant biopolymer on Earth, constitutes a substantial portion (40–60%) of wood mass, and can be obtained in the form of fibers ranging from 20–40 μm in thickness through pulping (Mao et al., 2017).
- Cellulose nanofibers (CNFs) are semi-crystalline spaghetti-like nanoparticles with a thickness of 5–30 nm and a length of a few micrometers (Mao et al., 2017).
- CNFs have high mechanical properties, biodegradability, and high surface area (Jami et al., 2019).
- We aim to produce nanofibers for enhanced insulation; CNF foams offer high porosity and small pores, reducing thermal conductivity as per Knudsen Effect.

Paper Waste - Cellulose Fibers



Cellulose Nanofibrils (CNFs)

Literature Review

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01 One study has thoroughly discussed the structural, morphological, and thermal properties of cellulose nanofibers produced from wastepaper, and their use as reinforcement in materials (Najafabadipoor et al., 2022).

02 Strong mechanical fibrillation is mostly used for the preparation of CNFs, depending on the properties of the raw materials (Zeng et al., 2021).

03 A variety of mechanical disintegration processes such as ultrasonication, high-speed mixing, ball milling, high-pressure homogenization, and cryocrushing have been employed to make CNFs (Nasir et al., 2022).

04 Ultrasonication generates high temperature, pressure, and shear force during the process due to sonic cavitation, promoting a significant reduction in particle size (Shahi et al., 2020).

05 Sulfuric acid hydrolysis is the most researched and extensively used pretreatment for producing CNFs (Vanderfleet et Cranston, 2021).

06 CNF composite foam has exceptional flame resistance and self-extinguishing properties, which increases the scope of CNF-based foam's use in energy-efficient buildings (Wang et al., 2019).

Literature Review

Gaps in the Existing Literature

01 Lack of tested research on recycled cellulose fibers from paper waste, with a few studies demonstrating applications of recycled fibers in construction materials.

02 Lack of research on optimum ultrasonication conditions including sonication time, sonication power, and concentration of paper waste required to ultrasonicate the paper waste into nanocellulose.

03 Lack of research on converting nanocellulose into foam material with low thermal conductivity.

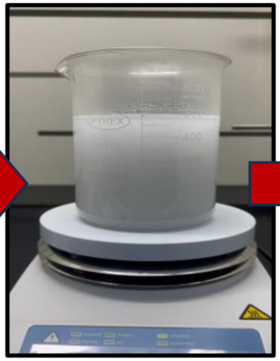
Cellulose Nanoparticles

Process Optimization

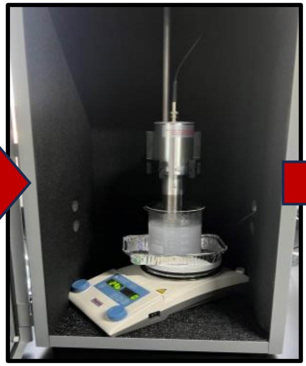
Stage 1: CNFs from Paper Waste

Stage 2: Insulation Foam from CNFs

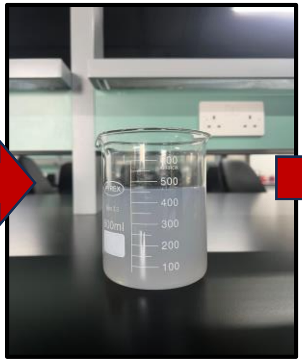
Paper Waste
(Broke Screen Reject)



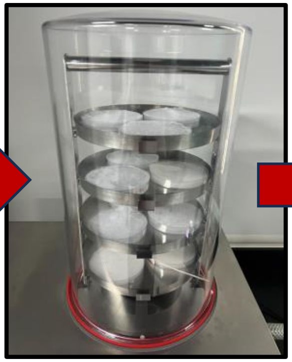
Sulfuric Acid Pretreatment
Conditions:
With/Without Pretreatment



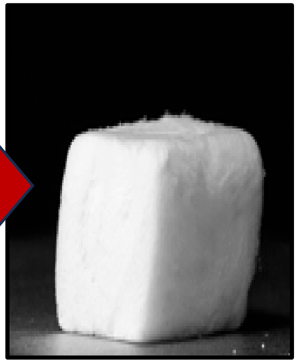
Ultrasonication
Conditions:
Power (120 or 60 W)
Time (10, 30, or 60 min)
Concentration (0.5 or 1.0%)



CNFs Suspension
Response:
Fibrillation Degree

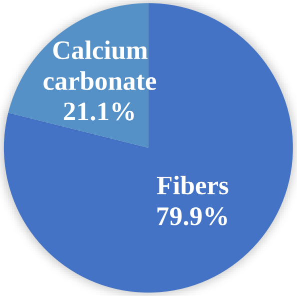


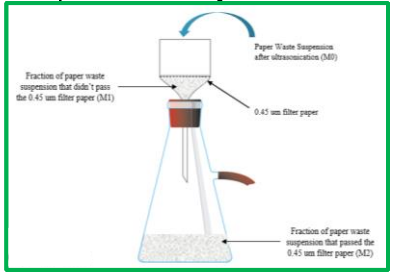
Freeze-Drying



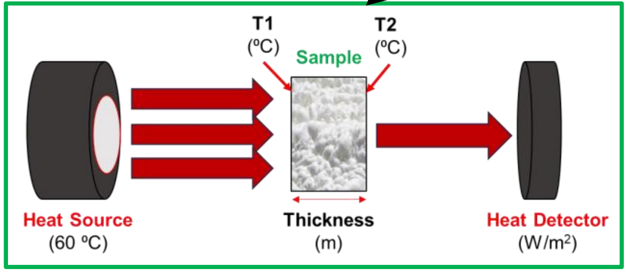
Insulation Foam
Response:
Thermal Conductivity

Composition





Fibrillation Degree (%) = $\frac{Mass\ CNFs}{Mass\ Used\ Paper\ Waste}$ *100%



Thermal Conductivity (W/m.K) = $\frac{Heat\ Flux * Thickness}{(T1-T2)}$

19 Ultrasonicated Paper Waste Samples under Different Conditions

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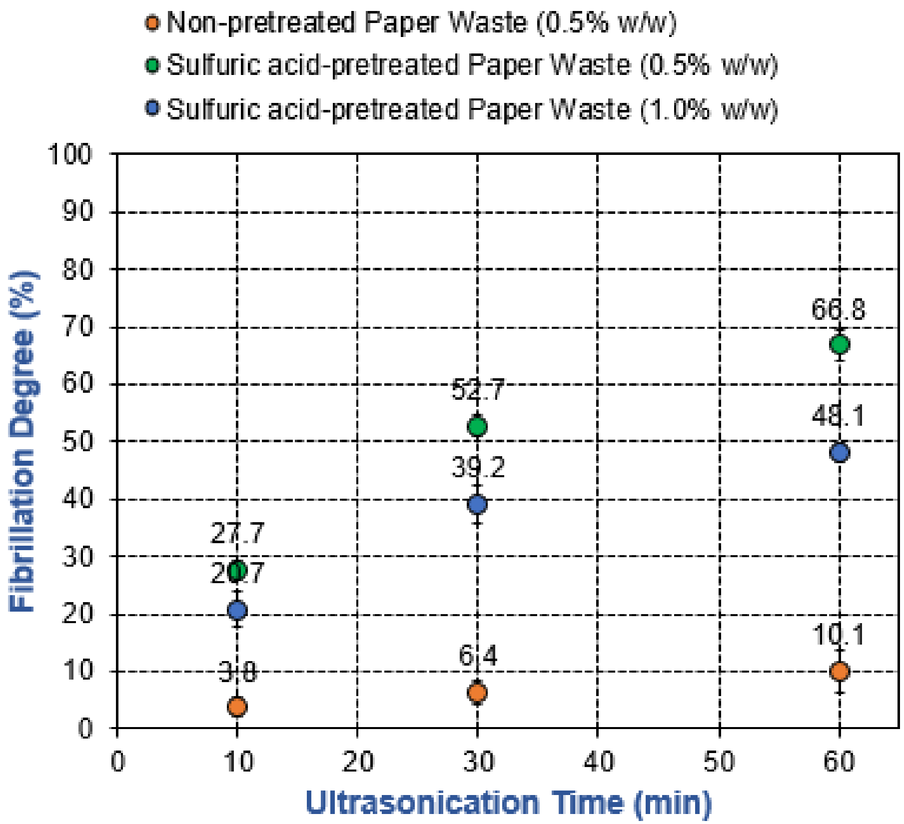
Pretreatment	Sample Concentration (%)	Power (W)	Time (minute)
Paper Waste	0.5%	-	-
Ultrasonicated Samples without Sulfuric Acid Pretreatment	0.5%	50% (60 W)	10 min
		50% (60 W)	30 min
		50% (60 W)	60 min
		100% (120 W)	10 min
		100% (120 W)	30 min
		100% (120 W)	60 min
Ultrasonicated Samples with Sulfuric Acid Pretreatment	0.5%	50% (60 W)	10 min
		50% (60 W)	30 min
		50% (60 W)	60 min
		100% (120 W)	10 min
		100% (120 W)	30 min
		100% (120 W)	60 min
Ultrasonicated Samples with Sulfuric Acid Pretreatment	1.0%	50% (60 W)	10 min
		50% (60 W)	30 min
		50% (60 W)	60 min
		100% (120 W)	10 min
		100% (120 W)	30 min
		100% (120 W)	60 min

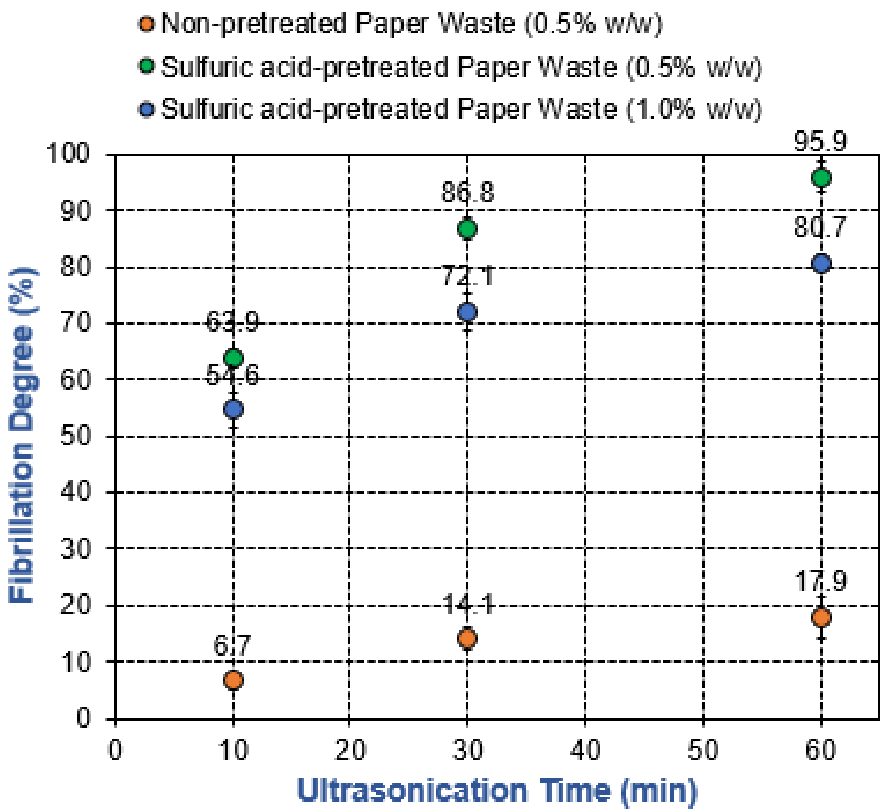
CNF Production Optimization – Fibrillation Degree

High fibrillation degree was obtained using:

- High ultrasonication power
- Sulfuric acid pretreatment
- Low paper waste concentration
- Prolonged ultrasonication time



50% Sonication Power – 60 W



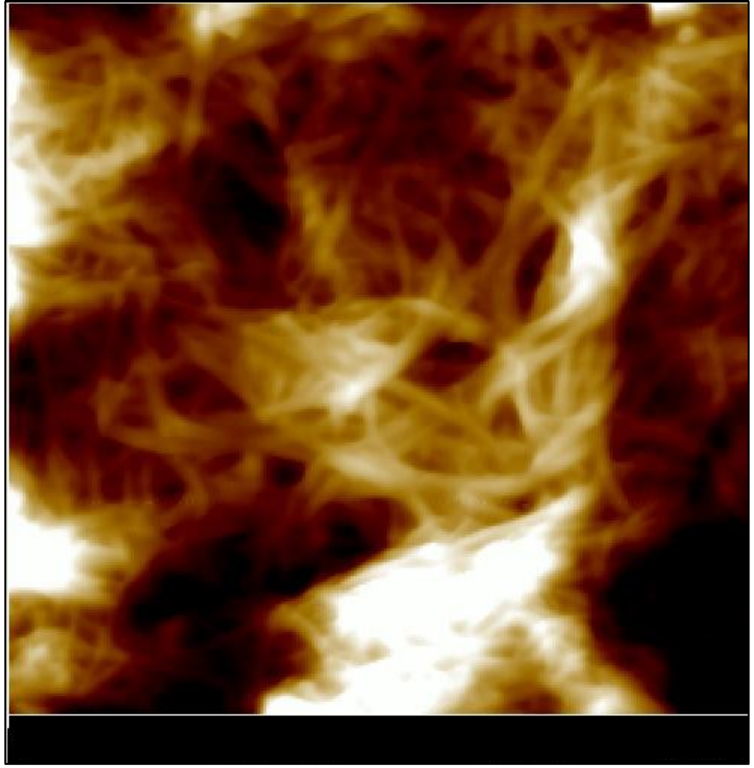
100% Sonication Power – 120 W

CNF Production Optimization – Fibrillation Degree

The efficiency of coupling ultrasonication with sulfuric acid pretreatment to produce CNFs from paper waste was confirmed using:

- Height photo using Atomic Force Microscopy (AFM)

Cellulose Nanofibers Thickness = 23.8 ± 7.4 nm



Characterization and Potential of the Produced CNF Foams as Insulation Materials

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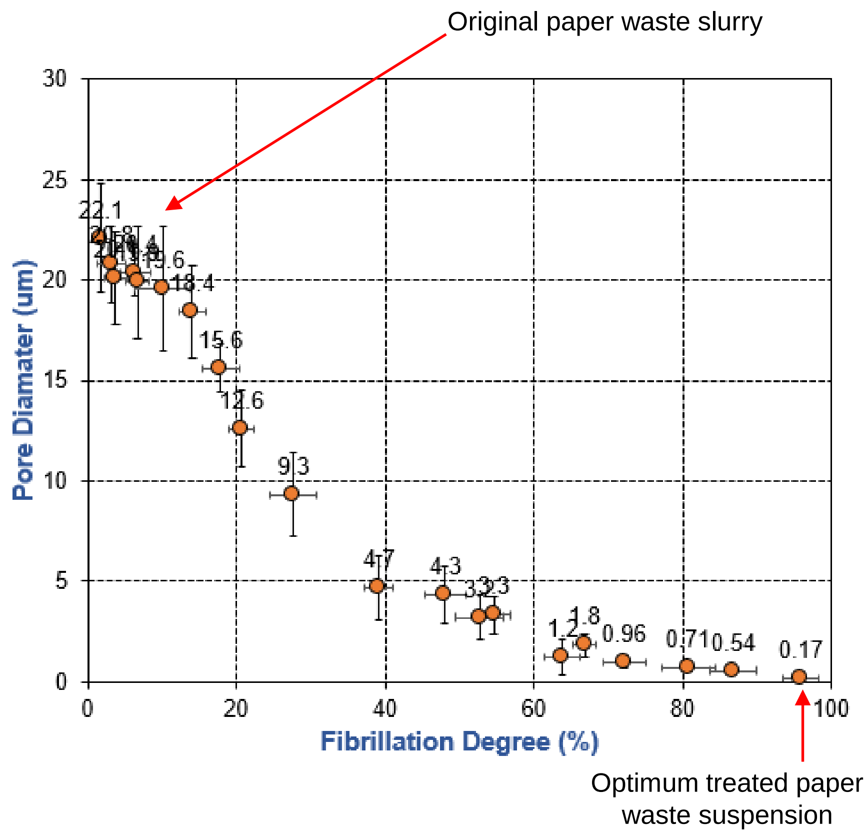
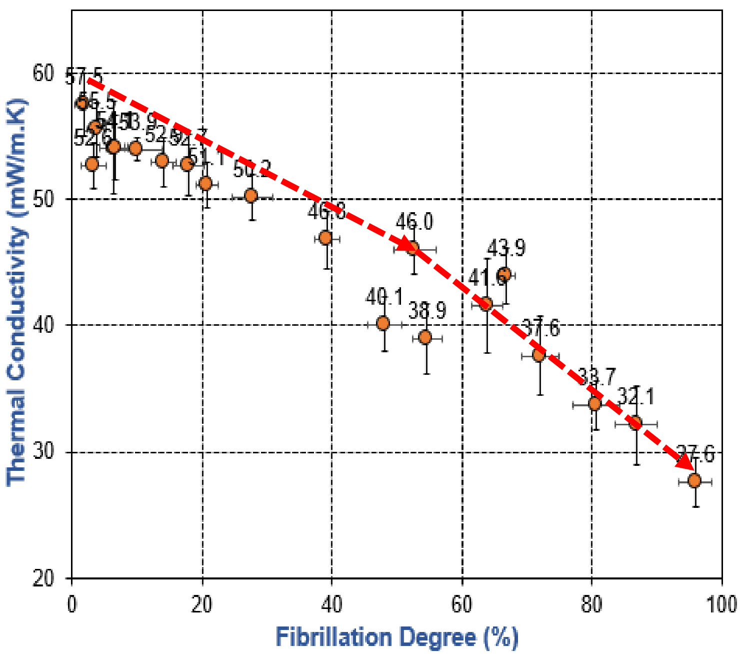
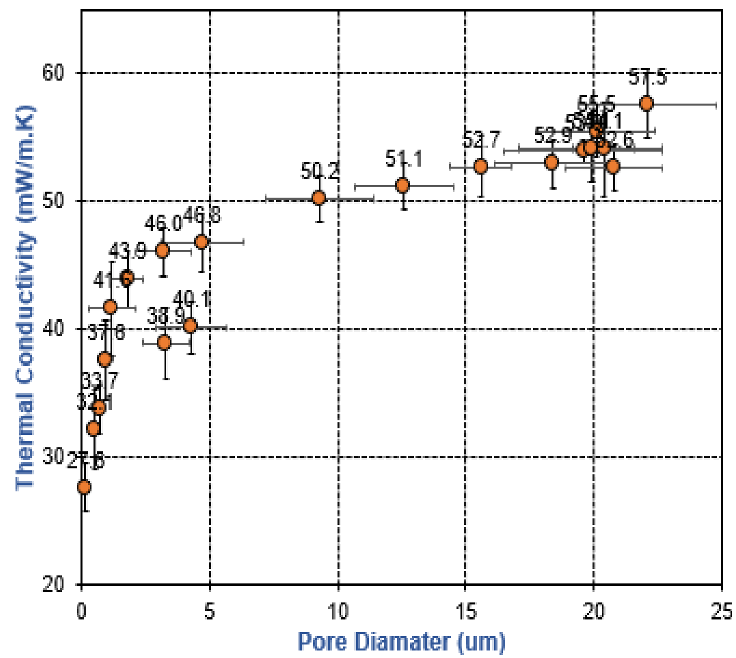
Density	Density = 5 mg/cm^3
Porosity	Total porosity (%) = 99.7%
Pore Diameter	The pore diameter of the foams was strongly dependent on the fibrillation degree (Mercury intrusion porosimetry).



Characterization and Potential of the Produced CNF Foams as Insulation Materials

- As the fibrillation degree increases, the thermal conductivity of the formed foam decreases because of the enhanced thermal insulation (Knudsen Effect).
- High fibrillation degree resulted in thermal conductivity of 27.6 ± 1.9 mW/m.K.
- This decrease in thermal conductivity suggests that foams have lower thermal conductivities with lower pore volume.





Cellulose Nanofibrils to Insulation Material

Major Findings

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Conversion of paper waste to cellulose nanofibrils using ultrasonication and sulfuric acid.

Optimization of the sonication time, sonication power, and concentration of paper waste.

Optimum conditions: 60 mins, 120 W, with sulfuric acid pretreatment.

Foam's thermal conductivity is impacted by sonication conditions.

The higher the fibrillation degree, the lower the thermal conductivity.

Insulation material thermal conductivity = 27.6 ± 1.9 mW/m.k (comparable to the insulation materials available in the market).

Construction Materials Out of Paper Waste

Research Output

On the Conversion of Paper Waste And Rejects into High-Value Materials and Energy, 2023, 15(8), 6915; https://doi.org/10.3390/su15086915

Sustainable Construction Materials towards Green Buildings, **To be submitted**

Mini-review about Ultrasonication to Make Cellulose Nanofibrils, **To be submitted**

The production of cellulose nanofibrils in high yield from paper waste using ultrasonication, **Manuscript in Preparation**

Low thermal conductivity insulation foams from paper waste, **Manuscript in Preparation**

References

1. Abdelhamid, H. N. et Mathew, A. P. (2022). Cellulose-Based Nanomaterials Advance Biomedicine: A Review. International Journal of Molecular Sciences, 23(10), 5405. https://doi.org/10.3390/ijms23105405
2. Abushammala, H., Hashaikeh, R., & Cooney, C. L. (2012). Microcrystalline cellulose powder tableting via networked cellulose-based gel material. Powder Technology, 217, 16–20. https://doi.org/10.1016/j.powtec.2011.10.002
3. Adam, A. A., Ojur Dennis, J., Al-Hadeethi, Y., Mkawi, E. M., Abubakar Abdulkadir, B., Usman, F., Mudassir Hassan, Y., Wadi, I. A. et Sani, M. (2020). State of the Art and New Directions on Electrospun Lignin/Cellulose Nanofibers for Supercapacitor Application: A Systematic Literature Review. Polymers, 12(12), 2884. https://doi.org/10.3390/polym12122884
4. Amorim, J. D. P. de, Souza, K. C. de, Duarte, C. R., Da Silva Duarte, I., Assis Sales Ribeiro, F. de, Silva, G. S., Farias, P. M. A. de, Stingl, A., Costa, A. F. S., Vinhas, G. M. et Sarubbo, L. A. (2020). Plant and bacterial nanocellulose: Production, properties and applications in medicine, food, cosmetics, electronics and engineering. A review. Environmental Chemistry Letters, 18(3), 851–869. https://doi.org/10.1007/s10311-020-00989-9
5. Blanco, A., Monte, M. C., Campano, C., Balea, A., Merayo, N. et Negro, C. (2018). Nanocellulose for Industrial Use. Handbook of Nanomaterials for Industrial Applications, 74–126. https://doi.org/10.1016/B978-0-12-813351-4.00005-5
6. De Azeredo, H. M. C., Da Silva Barud, H., Farinas, C. S., Vasconcellos, V. M., & Claro, A. M. (2019). Bacterial cellulose as a raw material for food and food packaging applications. *Frontiers in Sustainable Food Systems*, *3*. https://doi.org/10.3389/fsufs.2019.00007
7. Ferreira, F. V., Pinheiro, I. F., De Souza, S. F., Mei, L. H. I., & Lona, L. M. F. (2019). Polymer Composites Reinforced with Natural Fibers and Nanocellulose in the Automotive Industry: A Short Review. Journal of Composites Science, 3(2), 51. https://doi.org/10.3390/jcs3020051
8. Fuller, B., Fafitis, A. et Santamaria, J. (2006). Structural Properties of a New Material Made of Waste Paper. Architectural Engineering Conference (AEI) 2006, 1–16. https://doi.org/10.1061/40798(190)10
9. Fürtauer, S., Hassan, M. A., Elsherbiny, A. A., Gabal, S. A., Mehanny, S., & Abushammala, H. (2021). Current status of cellulosic and nanocellulosic materials for oil spill cleanup. *Polymers*, *13*(16), 2739. https://doi.org/10.3390/polym13162739
10. Gholipour, H. F., Arjomandi, A., & Yam, S. (2022). Green property finance and CO2 emissions in the building industry. Global Finance Journal, 51, 100696. https://doi.org/10.1016/j.gfj.2021.100696
11. Haile, A., Gelebo, G. G., Tesfaye, T., Mengie, W., Mebrate, M. A., Abuhay, A., & Limeneh, D. Y. (2021). Pulp and paper mill wastes: utilizations and prospects for high value-added biomaterials. Bioresources and Bioprocessing, 8(1). https://doi.org/10.1186/s40643-021-00385-3

References

12. Hospodarova, V., Singovszka, E., & Stevulova, N. (2018). Characterization of cellulosic fibers by FTIR spectroscopy for their further implementation to building materials. *American Journal of Analytical Chemistry*, *09*(06), 303–310. https://doi.org/10.4236/ajac.2018.96023
13. Jain, S. (2015). Utilization of waste paper sludge in construction industry. Indian Institute of Technology, Delhi. https://www.researchgate.net/profile/Sandeep-Jain-2/publication/279331560_Utilization_of_Waste_Paper_Sludge_in_Construction_Industry/links/5592457008ae47a34910dc11/Utilization-of-Waste-Paper-Sludge-in-Construction-Industry.pdf
14. Jami, Tarun; Karade, S.R.; Singh, L.P. (2019). *A review of the properties of hemp concrete for green building applications. Journal of Cleaner Production, (), 117852.* doi:10.1016/j.jclepro.2019.117852
15. Jiao, L., Su, M., Chen, L., Wang, Y [Yuangang], Zhu, H. et Dai, H. (2016). Natural Cellulose Nanofibers As Sustainable Enhancers in Construction Cement. PLOS ONE, 11(12), e0168422. https://doi.org/10.1371/journal.pone.0168422
16. Jung, Y. H., Chang, T., Zhang, H., Yao, C., Zheng, Q., Yang, V. W., Mi, H., Kim, M., Cho, S. J., Park, D. W., Jiang, H., Lee, J., Qiu, Y., Zhou, W., Cai, Z., Gong, S., & Ma, Z. (2015). High-performance green flexible electronics based on biodegradable cellulose nanofibril paper. Nature Communications, 6(1). https://doi.org/10.1038/ncomms8170
17. Li, M.-C., Wu, Q., Song, K., Lee, S., Qing, Y. et Wu, Y. (2015). Cellulose Nanoparticles: Structure–morphology–rheology Relationships. ACS Sustainable Chemistry & Engineering, 3(5), 821–832. https://doi.org/10.1021/acssuschemeng.5b00144
18. Liu, J., Chen, P., Qin, D., Jia, S., Jia, C., Li, L., Bian, H., Wei, J. et Shao, Z. (2020). Nanocomposites membranes from cellulose nanofibers, SiO2 and carboxymethyl cellulose with improved properties. Carbohydrate Polymers, 233, 115818. https://doi.org/10.1016/j.carbpol.2019.115818
19. Liu, T., Chen, L., Yang, M., Sandanayake, M., Miao, P., Yang, S., & Yap, P. (2022). Sustainability Considerations of Green Buildings: A detailed overview on current advancements and future considerations. Sustainability, 14(21), 14393. https://doi.org/10.3390/su142114393
20. Low, Z. L., Low, D. Y. S., Tang, S. Y., Manickam, S., Tan, K. W. et Ban, Z. H. (2022). Ultrasonic cavitation: An effective cleaner and greener intensification technology in the extraction and surface modification of nanocellulose. Ultrasonics Sonochemistry, 106176.
21. Mao, J., Abushammala, H., Brown, N. R., & Laborie, M. P. (2017). Comparative Assessment of Methods for Producing Cellulose I Nanocrystals from Cellulosic Sources. In Acs Symposium Series (pp. 19–53). https://doi.org/10.1021/bk-2017-1251.ch002
22. Najafabadipoor, M., Abbaslou, H. et Bakhtiari, S. (2022). Structural, morphological, and thermal properties of cellulose nanofibers extracted from waste paper. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-2026708/v1

References

23. Nasir, M., Aziz, M. A., Zubair, M., Manzar, M. S., Ashraf, N., Mu'azu, N. D. et Al-Harthi, M. A. (2022a). Recent review on synthesis, evaluation, and SWOT analysis of nanostructured cellulose in construction applications. Journal of Building Engineering, 46, 103747. https://doi.org/10.1016/j.jobe.2021.103747
24. Nasir, M., Aziz, M. A., Zubair, M., Manzar, M. S., Ashraf, N., Mu'azu, N. D. et Al-Harthi, M. A. (2022b). Recent review on synthesis, evaluation, and SWOT analysis of nanostructured cellulose in construction applications. Journal of Building Engineering, 46, 103747. https://doi.org/10.1016/j.jobe.2021.103747
25. Nouman khan Usama. (2021). Effect of Paper Waste as Cement Replacement in Rammed Earth Construction (Vol. 9). https://www.researchgate.net/publication/363520340_Effect_of_Paper_Waste_as_Cement_Replacem https://doi.org/10.30534/ijeter/2021/05972021
26. Okeyinka Oriyomi, M., Oloke David, A. et Khatib, J. (2015). A review of recycled use of post consumer waste paper in construction. Academic Journal of Civil Engineering, 33(2), 711–717. https://doi.org/10.26168/icbbm2015
27. Oriyomi, M. O., David, A., & Khatib, J. (2015). A review of recycled use of post consumer waste paper in construction. *Academic Journal of Civil Engineering*, *33*(2), 711–717. https://doi.org/10.26168/icbbm2015.111
28. Pandey, A. (2021). Pharmaceutical and biomedical applications of cellulose nanofibers: A review. Environmental Chemistry Letters, 19(3), 2043–2055. https://doi.org/10.1007/s10311-021-01182-2
29. Pirani, S. I., & Hashaikeh, R. (2013). Nanocrystalline cellulose extraction process and utilization of the byproduct for biofuels production. Carbohydrate Polymers, 93(1), 357–363. https://doi.org/10.1016/j.carbpol.2012.06.063
30. Raoelivololona, T., Ramaroson, M. et Raminosoa, C. (2020). Paper recycling for the making of constructions materials. MATEC Web of Conferences, 307, 1041. https://doi.org/10.1051/matecconf/202030701041
31. Rojas, J., Bedoya, M. et Ciro, Y. (2015). Current trends in the production of cellulose nanoparticles and nanocomposites for biomedical applications. Cellulose-Fundamental Aspects and Current Trends, 193–228.
32. Roy, S., Kim, H. C., Panicker, P. S., Rhim, J.-W. et Kim, J. (2021). Cellulose Nanofiber-Based Nanocomposite Films Reinforced with Zinc Oxide Nanorods and Grapefruit Seed Extract. Nanomaterials, 11(4), 877. https://doi.org/10.3390/nano11040877
33. Shahi, N., Min, B., Sapkota, B. et Rangari, V. K. (2020). Eco-Friendly Cellulose Nanofiber Extraction from Sugarcane Bagasse and Film Fabrication. Sustainability, 12(15), 6015. https://doi.org/10.3390/su12156015
34. Shakir, A., Naganathan, S., & Mustapha, K. (2013). Development of Bricks from waste material: A review paper. ResearchGate. https://www.researchgate.net/publication/306279418_Development_of_Bricks_from_waste_material_A_review_paper

References

35. Shibib, K. S. (2015). Effects of waste paper usage on thermal and mechanical properties of fired brick. Heat and Mass Transfer, 51(5), 685–690. https://doi.org/10.1007/s00231-014-1438-6
36. Sutcu, M., Del Coz Díaz, J. J., Rabanal, F. P. Á., Gencel, O., & Akkurt, S. (2014). Thermal performance optimization of hollow clay bricks made up of paper waste. Energy and Buildings, 75, 96–108. https://doi.org/10.1016/j.enbuild.2014.02.006
37. Sign, X. (2023, March 21). 10 paper waste facts you need to know | Eversign. Xodo Sign Blog. https://blog.eversign.com/paper-waste-facts/#:~:text=85%20Million%20Tons%20of%20Paper%20Waste%20Created%20Each%20Year&text=Most%20of%20these%20documents%20are,pounds%20of%20paper%20per%20personThakur, V. K., Frollini, E. et Scott, J. L. (2020). Cellulose nanoparticles. Chemistry and fundamentals (1st, Vol. 1). Royal Society of Chemistry. https://doi.org/10.1039/9781788019521
38. Vanderfleet, O. M. et Cranston, E. D. (2021). Production routes to tailor the performance of cellulose nanocrystals. Nature Reviews Materials, 6(2), 124–144. https://doi.org/10.1038/s41578-020-00239-y
39. Vijay Kumar Thakur, Elisabete Frollini, & Scott, J. (2021). In Cellulose Nanoparticles : Chemistry and Fundamentals. Royal Society of Chemistry. https://doi.org/10.1039/9781788019521
40. Wang, D., Feng, X., Zhang, L., Li, M., Liu, M., Tian, A. et Fu, S. (2019). Cyclotriphosphazene-bridged periodic mesoporous organosilica-integrated cellulose nanofiber anisotropic foam with highly flame-retardant and thermally insulating properties. Chemical Engineering Journal, 375, 121933. https://doi.org/10.1016/j.cej.2019.121933
41. Xie, H., Du, H., Yang, X. et Si, C. (2018a). Recent Strategies in Preparation of Cellulose Nanocrystals and Cellulose Nanofibrils Derived from Raw Cellulose Materials. International Journal of Polymer Science, 2018, 1–25. https://doi.org/10.1155/2018/7923068
42. Xie, H., Du, H., Yang, X. et Si, C. (2018b). Recent strategies in preparation of cellulose nanocrystals and cellulose nanofibrils derived from raw cellulose materials. International Journal of Polymer Science, 2018.
43. Zainab Hasan et Layth AbdulRasool Alasadi (2020). Evaluation of Suitability of Cement Mortar Including Paper Waste as Construction Materials. Journal of Green Engineering, 10(6), 3206–3223. https://www.researchgate.net/publication/344599591_Evaluation_of_Suitability_of_Cement_Mortar_Including_Paper_Waste_as_Construction_Materials
44. Zeng, J., Zeng, Z., Cheng, Z., Wang, Y [Yu], Wang, X., Wang, B. et Gao, W. (2021). Cellulose nanofibrils manufactured by various methods with application as paper strength additives. Scientific Reports, 11(1), 11918. https://doi.org/10.1038/s41598-021-91420-y
45. Zhou, Hui, et al. "Interactions of three municipal solid waste components during co-pyrolysis." Journal of analytical and applied pyrolysis 111 (2015): 265-271.

Thank you

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Thank You for Your Attention!

Saydah Ahmed (1078157) and **Aya Yassine (1081668)**
Dr. Hatem Abushammala hatem.abushammala@adu.ac.ae