Exploring Seaweed-Based Porous Foam as a Green Strategy for Stormwater Management

Exploration d'une mousse poreuse à base d'algues comme stratégie verte pour la gestion des eaux pluviales

Richa Sharma[a*], Ana Barcot[b], I. A. Sofia Larsson[b], Lian Lundy[c], Linn Berglund[a]

[a]Division of Materials Science, Department of Engineering Sciences and Mathematics, Luleå University of Technology - richa.sharma@associated.ltu.se
[b]Division of Fluid and Experimental Mechanics, Department of Engineering Sciences and Mathematics, Luleå University of Technology
[c]Division of Architecture and Water, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology

RÉSUMÉ

Les stipes d'algues brunes ont été utilisées pour fabriquer des matériaux poreux légers destinés à la gestion des eaux pluviales dans les systèmes d'infrastructures vertes tels que les toits végétalisés, mais également les bassins d'infiltration et les rigoles végétalisées. Laminaria digitata a été fibrillée, gelée par congélation et réticulée au $CaCl_2$ pour produire des mousses poreuses stables. L'échantillon optimisé présentait une porosité d'environ 90 %, une bonne stabilité mécanique en milieu humide (~4 kPa) et de fortes capacités d'absorption (~2800 % pour l'eau déionisée et ~3000 % pour l'eau de ruissellement). La microtomographie a confirmé une structure poreuse interconnectée, et les tests d'absorption cycliques ont démontré la réutilisabilité du matériau. La germination de graines sur le matériau a également confirmé son potentiel en tant que couche absorbante biodégradable et compatible avec les plantes. Dans l'ensemble, cette mousse poreuse à base d'algues constitue une solution innovante et naturelle pour améliorer la rétention des eaux pluviales sur les toits végétalisés.

ABSTRACT

Stipes of the brown seaweed *Laminaria digitata* were used to fabricate a lightweight porous material for use in stormwater management e.g. as a compliment to nature-based solutions in space-limited environments. Sections of *L. digitata* were fibrillated, freeze-cast, and $CaCl_2$ crosslinked to produce structurally stable porous foams. The optimized sample showed ~90% porosity, good wet mechanical stability (~4 kPa), and high absorption capacities of ~2800% (deionized water) and ~3000% (stormwater). Microtomography confirmed an interconnected pore structure, and cyclic absorption tests demonstrated reusability. Seed germination on the material further supported its potential as a plant-compatible, biodegradable absorbent layer. Overall, the seaweed-based porous foam offers a promising nature-based solution for enhancing stormwater retention in e.g. green roof applications.

KEYWORDS

Seaweed, stormwater management, resource-efficient biobased material, sustainibility

General presentation of the operation/strategy

1 BACKGROUND

Seaweed-based porous materials offer potential to provide a sustainable biopolymer approach for improving stormwater management in green infrastructure. The term sustainable drainage encompasses a range of system types (schematically represented in figure 1) such as green roofs, bioretention cells, infiltration basins, and swales. (Li et al., 2019) Their natural polysaccharides (alginate and cellulose) enable the formation of lightweight, highly porous foams capable of absorbing and retaining large volumes of water. In green roofs, such materials can function as light weight and efficient absorbent layers that capture, store, and gradually release stormwater, reducing runoff pressure on urban drainage systems while supporting plant growth. Their biodegradability, low density, and strong capillary action make them well suited for eco-friendly and climate-resilient design.

Objectives of this study include:

- Developing seaweed into a porous multifunctional structure
- Crosslinking to obtain a mechanically stable wet sponge
- Evaluating deionized water and stormwater absorption performance
- Assessing seed germination compatibility on the porous material

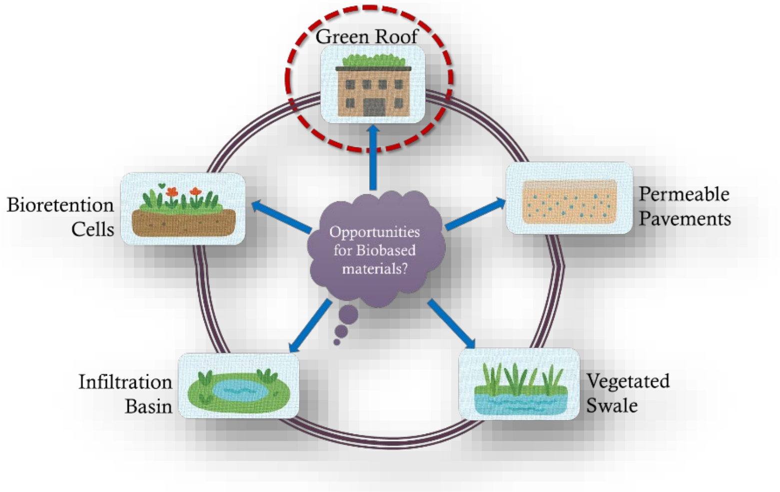

Figure 1. Schematic representation of the possibility of using biopolymers within sustainable stormwater management infrastructure.

2 METHODOLOGY

The methodology encompasses a non-toxic approach for the material development from brown seaweed stipes (*Laminaria digitata*) to porous seaweed-based structures. The seaweed was directly fibrillated using an MKZA6-3 ultrafine friction grinder (SiC stones, 1500 rpm), without any chemical pretreatment. The resulting paste was diluted with water to obtain different concentrations, cast into cylindrical molds, and frozen overnight at -23 °C. The frozen samples were then freeze-dried for 48 h at 1 mbar to form porous foams. The dried structures were crosslinked by immersing them in a 3 wt.% $CaCl_2$ aqueous solution overnight, washed with water to remove excess ions, and freeze-dried again to obtain the final stabilized samples. Physicochemical characterizations included porosity measurement, compression testing, and absorption studies in deionized water and stormwater. Cyclic stormwater absorption tests assessed reusability. Microstructure was examined using X-ray microtomography (XMT), and material compatibility with plant growth was evaluated through chia seed germination.

3 RESULTS AND DISCUSSION

The stipes of brown seaweed were chopped and premixed into a paste, as depicted in Figure 2a. This premix was subsequently diluted with water prior to the fibrillation process. The resulting micro-fibrous paste (SF) contained approximately 6 wt.% dry content. To obtain samples with varying solid concentrations, the SF was further diluted to prepare suspensions of 5, 2.5, and 1 wt.%., that subsequently were freeze-casted. The fabrication procedure is schematically illustrated in Figure 2b, and photographs of the resulting freeze-dried samples S5, S2.5, and S1 are shown in Figure 2c. Based on physical appearance (uniform cylindrical geometry), surface characteristics (visible porous structure), and preliminary handling tests, the S2.5 sample demonstrated the most favourable integrity and workability among the three compositions. Therefore, S2.5 was selected as the optimized formulation for detailed characterization. To introduce ionic crosslinking, the freeze-dried samples were immersed overnight in a 3 wt.% aqueous $CaCl_2$ solution. The crosslinked samples were then thoroughly rinsed with deionized water to remove excess crosslinker, followed by refreezing and a second freeze-drying step to obtain the final crosslinked materials. The crosslinked S2.5 sample exhibited excellent water stability and a water absorption capacity of approximately 2800%. Interestingly, the stormwater absorption capacity was slightly higher around 3000%. This increase may be attributed to the presence of metal ions and organic matter mobilized by rainfall runoff, which can be additionally adsorbed by the material, leading to enhanced absorption (Zhu et al., 2022). Mechanical stability in the wet state was assessed under compression loading. The S2.5 scaffold sustained a compressive stress of ~4 kPa at 50% strain, indicating adequate mechanical robustness for handling and practical use without breaking the structure. Such durability is critical for the long-term performance in variable weather conditions. The porosity, determined using a liquid displacement method, was ~90%, aligning well with porosity values reported for other alginate-based porous structures.

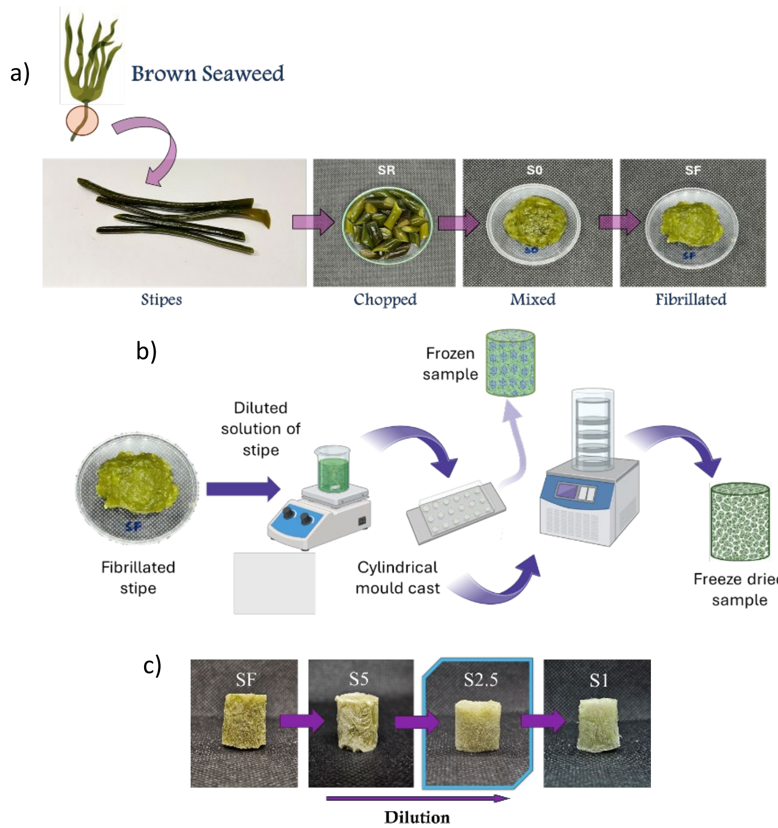

Figure 2. Processing of stipes of brown seaweed into fibrillated paste a), Schematic representation of assembling porous network by freeze drying method b) and c) photographs of freeze-dried materials with different solid concentration.

The morphology and internal porous architecture were investigated using X-ray micro tomography (XMT). As shown in Figure 3a, a’, a’’, and a’’’, the 3D reconstruction revealed a highly interconnected pore network with a random but homogeneous distribution throughout the sample. Such architecture is advantageous for water absorption, retention, and potential root penetration in green-infrastructure applications. Cyclic deionized and stormwater absorption tests were performed for three consecutive absorption–drying cycles. This robust cyclic absorption behaviour demonstrated the reusability of the material is not limited to single use but could function over many rain/dry cycles. The results indicated that S2.5 retained excellent structural integrity and showed consistent absorption performance across cycles, confirming its reusability (bar graph shown in Figure 3b).

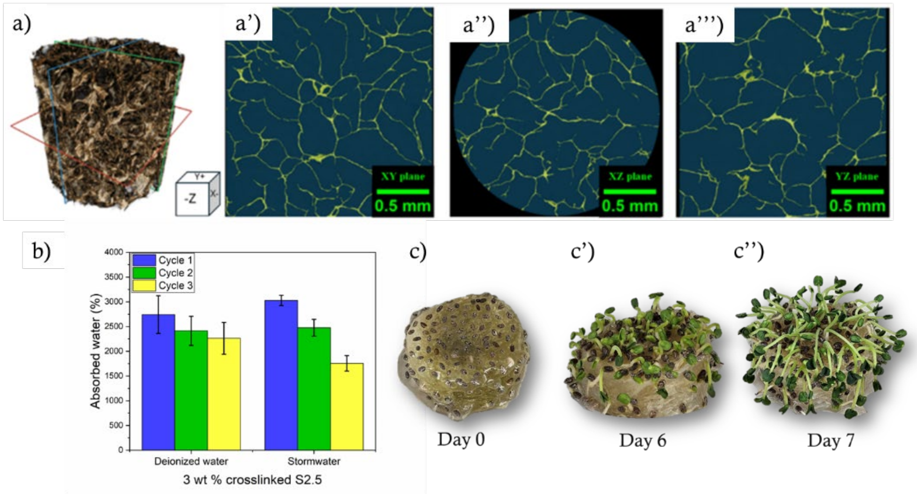

Figure 3. 3D-reconstruction images from XMT of crosslinked S2.5 a, a', a'' and a'''), Cyclic deionized and stormwater absorption values b) and photographs of seed germination process at day 0 c), day 6 c') and day 7 c'')

Overall, the results demonstrate that the fabricated porous material shows promising potential as a bio-based substrate for green rooftop applications. To further assess its applicability in green infrastructure, seed germination studies were conducted. Pre-soaked chia seeds were spread onto water-saturated S2.5 samples (Figure 3c, c' and c''). The successful germination observed supports the suitability of the developed bio-based porous scaffold as a growth medium in rooftop vegetation systems.

4 CONCLUSION

This study demonstrated the development of a highly porous, seaweed-based material with excellent water uptake, mechanical stability, and reusability. The optimized S2.5 formulation exhibited ~90% porosity, strong wet integrity with compressive stress around 4 kPa, and high absorption capacities of ~2800% for deionized water and ~3000% for stormwater. Micro-CT analysis confirmed a well-interconnected pore architecture, while cyclic absorption tests verified material durability over multiple use cycles. Furthermore, successful chia seed germination on the hydrated scaffold highlights its potential as a bio-based substrate for green rooftop systems. Overall, the results indicate that brown seaweed-derived porous material is a promising, resource-efficient candidate for stormwater management as green infrastructure strategy.

5 REFERENCES

Li, C., Peng, C., Chiang, P. C., Cai, Y., Wang, X., & Yang, Z. (2019). Mechanisms and applications of green infrastructure practices for stormwater control: A review. *Journal of Hydrology*, *568*, 626–637. https://doi.org/10.1016/J.JHYDROL.2018.10.074

Zhu, P., Knoop, O., & Helmreich, B. (2022). Interaction of heavy metals and biocide/herbicide from stormwater runoff of buildings with dissolved organic matter. *Science of The Total Environment*, *814*, 152599. https://doi.org/10.1016/J.SCITOTENV.2021.152599