JFAChE
Journal of Fundamentals and Applications of Chemical Engineering

Communication

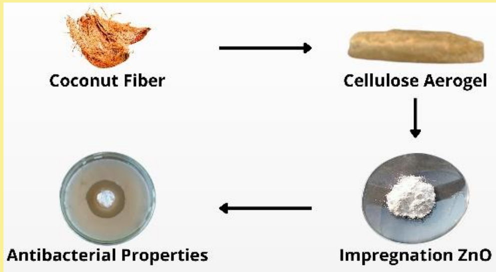
iptek.its.ac.id/index.php/ekstrak

Cellulose Aerogel with Zinc Oxide for Wound Dressing Application

Cholivia Hayyu Salsabila[1], Nur Shiyama Purnama Sari[1], Heru Setyawan[1], W. Widiyastuti[1], Ni Made Intan Putri Suari[1,*]

Received October 24, 2023; Revised January 22, 2024; Accepted August 21, 2024; Available online August 31, 2024
DOI: 10.12962/j2964710X.v5i1.19169

***Abstract*—** The aim of this research is to determine the performance of coconut fiber-based cellulose aerogel impregnated with zinc oxide for wound dressing applications. Cellulose is an alternative material in aerogel synthesis. Cellulose aerogel is the latest third-generation aerogel research, which has attracted much attention due to its good prospects, especially in terms of environmental friendliness and price effectiveness. The synthesis of cellulose aerogel begins with the cellulose purification stage through delignification and bleaching, followed by the addition of NaOH-urea solution, freeze drying and the final stage is impregnation with zinc oxide. Zinc oxide (ZnO) has nontoxic, safe and biocompatible properties and functions as an antibacterial agent. The cellulose/ZnO aerogel formed was subjected to performance tests including analysis of porosity, water absorption capacity, water vapor permeability and antibacterial tests. It was found that coconut fiber-based cellulose aerogel impregnated with ZnO has a good potential as a wound dressing application. The porosity of the resulting cellulose aerogel can reach above 90% with high water absorption capacity. Furthermore, a water vapor permeability can reach above 0,81 gr/cm^2.h and increases with enhancement of cellulose concentration. Antibacterial tests show that the cellulose/ZnO aerogel has good antimicrobial characteristics where antibacterial zone was formed around the sample.



***Keywords*—** Aerogel, Cellulose, Wound dressing, Zinc oxide

I. Introduction

Open wounds result from the damage or loss of external body tissue caused by factors that disrupt the body's protective system. The body responds to wounds through the wound healing process [1], which encompasses various types, including wound dressing. Current research in wound dressings involves the utilization of nanometer-sized particles, commonly referred to as nanoparticles. Modern wound dressings with bioactive polymer materials can increase effectiveness in wound care. One of the bioactive polymer materials that comes from nature is cellulose. Cellulose is a compound that is colourless, tasteless and has good physical and chemical properties, such as strong mechanical strength, good hydrophobicity, biocompatibility and non-toxicity. Therefore, it can be used in various applications.

Cellulose can stimulate the growth of granulation tissue and epithelial tissue to speed up the wound healing process [2]. Cellulose can be synthesized from various materials, one of which is coconut fiber. Coconut fiber from coconut plantation waste which is rich in cellulose and is available in nature in abundant quantities has the potential to synthesize cellulose nanoparticles [3]. Cellulose aerogel is a new material that has great potential in adsorption applications, oil/water separation, heat insulation, biomedical materials, metal/metal oxide nanoparticle carriers, carbon aerogel manufacture and many others [4].

Antimicrobial substances that have the ability to produce reactive oxygen species (ROS) can be applied in wound healing and preventing wound infections, one of which is ZnO. ZnO nanomaterials can produce ROS which are good antimicrobial agents. ZnO is nontoxic, safe and biocompatible. ZnO can accelerate wound healing by remaining topically at the wound site for a relatively long time. Zn^{2+} released from a kind of nano system can stimulate the production of fibroblasts and immune cells which play an important role in skin regeneration, and break down bacterial cell membranes [5], [6]. In this study,

[1] Departement of Chemical Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo, Surabaya, 60111, Indonesia. *E-mail: madeintan@chem-eng.its.ac.id

a cellulose aerogel was synthesized from coconut fiber impregnated with ZnO for potential use as a wound dressing.

II. Method

There are three main steps in this research. The first step is the synthesis of cellulose aerogel from coconut fiber. The next step is impregnation of ZnO into cellulose aerogel. The final step is the performance test of cellulose/ZnO aerogel for wound dressing applications.

The cellulose aerogel synthesis begins with the coconut fiber delignification process. This process is carried out by mixing coconut fiber into a NaOH solution for 2 hours at a temperature of 100°C. Next, the bleaching process was carried out for 1 hour by adding H_2O_2 solution. The cellulose pulp was then mixed with NaOH-urea solution for 30 minutes, followed by a gelation stage for 24 hours and a freeze drying stage. This study on the manufacture of cellulose hydrogels is based on work done by Fauziyah, et al. [3].

The cellulose aerogel formed is then impregnated with a ZnO solution and performance tests are carried out, including analysis of porosity, water absorption capacity, water vapor permeability and antibacterial tests. The antibacterial test was carried out using agar disc diffusion method. The antibacterial activity of the sample was determined by measuring the bacteria-free zone that formed around the sample which incubated for 24 hours.

III. Results and Discussion

The synthesized cellulose aerogel appears brown and fibrous as seen in Figure 1. Variations in cellulose concentration affect the porosity and density of the cellulose aerogel formed. The aerogel porosity tends to increase as the cellulose concentration used was increases. The cellulose concentration of 4.16%; 5.92% and 7.71% has a porosity of 91.47%; 93.84% and 98.21%, respectively. This increasing pattern can be caused by the increasing concentration of cellulose, the greater the possibility of forming good cellulose crosslink bonds until the crosslink solution reaches the limit of dissolving cellulose. However, when adding a higher concentration of 9.44%, the aerogel porosity actually decreased to 88.91%. This decline might be attributed to an excess of cellulose concentration in relation to the available solvent, impeding proper crosslinking processes [7].

Figure 1. Physical appearance of cellulose aerogel

Cellulose aerogel as a wound dressing matrix needs to have high absorption capacity to absorb exudate in the wound. The water absorption capacity of cellulose aerogel was increases with the increasing of cellulose concentration. However, for higher concentration of cellulose (9.44%), there was a decrease in absorption capacity, can be seen in Figure 2. This is related to the porosity value that was previously identified (Figure 3). The higher porosity allows more space to be available for the cellulose aerogel to absorb water, resulting in an increase in the water absorption capacity value [8].

The produced cellulose aerogel demonstrates an impressive water absorption capacity of up to 9 times, highlighting the potential of the synthesized cellulose aerogel-based wound dressing for effective wound healing. This capability enables the absorption of exudates up to 9 times the initial weight of the wound dressing matrix.

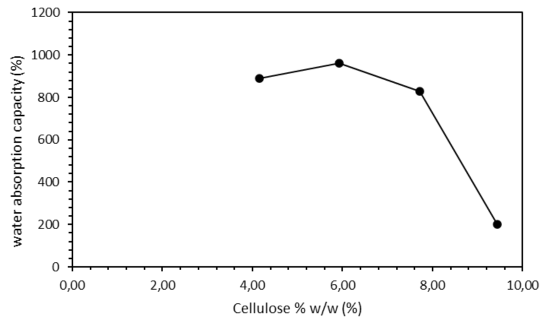


Figure 2. Effect of cellulose concentration on water absorption capacity of cellulose aerogel

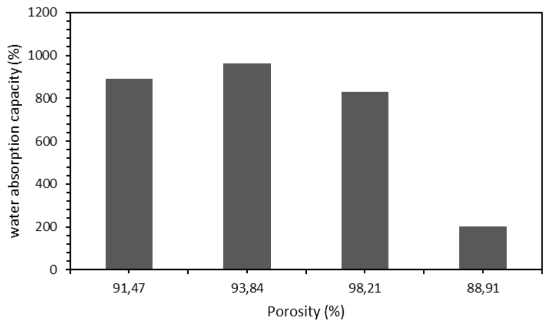


Figure 3. Effect of porosity on water absorption capacity of cellulose aerogel

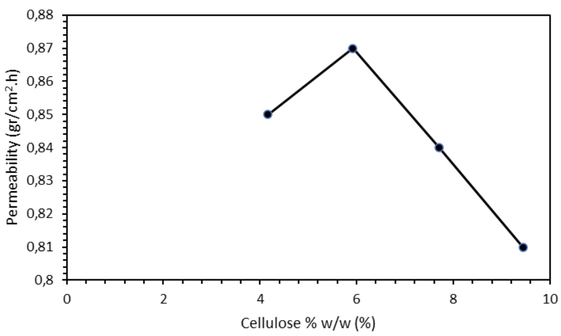


Figure 4. Effect of cellulose concentration on the permeability of cellulose aerogel

Figure 4 shows the effect of cellulose concentration on the water vapor permeability of cellulose aerogel. This shows that the water vapor permeability characteristics of the aerogel are also consistent with the porosity of the aerogel (Figure 5). The decreasing pattern occurs in variables above the concentration of 9.44%. The reduction in the permeability of the cellulose aerogel can be attributed to its relatively low porosity. This results in the pores, which serve as pathways for gas exchange, needing to be sufficiently large.

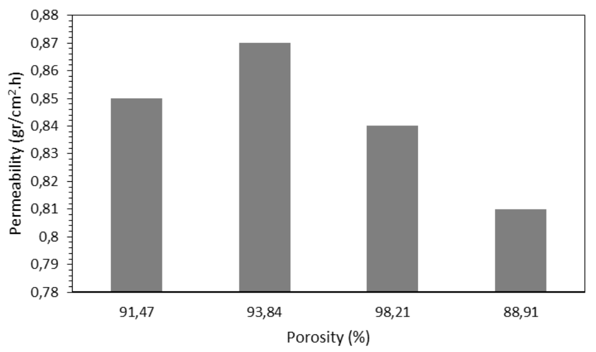


Figure 5. Effect of cellulose porosity on the permeability of cellulose aerogel

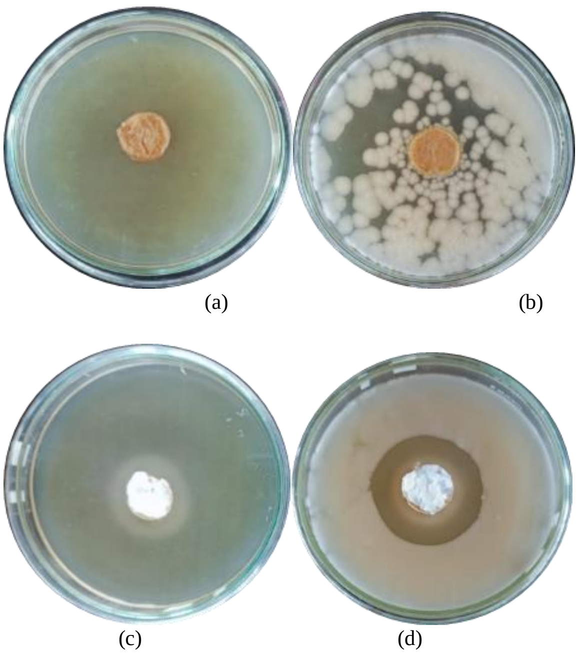


Figure 6. Results of antibacterial properties of cellulose aerogel (a) blank (b) 7.71%; (c) blank (d) 7.71% + ZnO

Testing of the anti-microbial properties of cellulose aerogel was carried out using the agar disc diffusion method. In this test, the cellulose aerogel sample was placed on NBA media which had been planted with the bacteria that most often infect wounds, namely *Eschericia coli* bacteria [9]. Cellulose aerogel samples were also placed on NBA media that was not planted with bacteria as a comparison (blank). There were 2 samples analyzed, 7.71% cellulose aerogel sample and 7.71% cellulose aerogel sample + ZnO. Anti-microbial testing was carried out for 24 hours with 1 time observation. It was found that in the cellulose aerogel samples with the addition of ZnO, an antibacterial zone was formed around the samples. Meanwhile, in samples without the addition of ZnO, anti-microbial zone was not formed around the sample. This shows that ZnO impregnated in cellulose aerogel was capable as an antimicrobial agent.

IV. CONCLUSION

The resulting coconut fiber-based cellulose aerogel impregnated with ZnO has a good potential for wound dressing application. The porosity of the resulting cellulose aerogel reaches 98% with high water absorption capacity and high water vapor permeability. It also has antimicrobial characteristic that can last for 24 hours.

V. ACKNOWLEDGEMENT

This work was supported by Department Research Grant 2023 (1315/PKS/ITS/2023) provided by Department of Chemical Engineering, Faculty of Industrial Technology and Systems Engineering, Sepuluh Nopember Institute of Technology.

VI. REFERENCES

[1] S. M. Iwan Antara Suryadi, AAGN Asmarajaya, “Wound Healing and Management Process,” e-Journal Med. Udayana, vol. 2, no. 2, pp. 1–19, 2013.
[2] M. Mir et al., “Synthetic polymeric biomaterials for wound healing: a review,” Prog. Biomater., vol. 7, no. 1, pp. 1–21, 2018, doi: 10.1007/s40204-018-0083-4.
[3] M. Fauziyah, W. Widiyastuti, R. Balgis, and H. Setyawan, “Production of cellulose aerogels from coir fibers via an alkali–urea method for sorption applications,” Cellulose, vol. 26, no. 18, pp. 9583–9598, 2019, doi: 10.1007/s10570-019-02753-x.
[4] J. Simon, H. P. Müller, R. Koch, and V. Müller, “Thermoplastic and biodegradable polymers of cellulose,” Polym. Degrad. Stab., vol. 59, no. 1–3, pp. 107–115, 1998, doi: 10.1016/s0141-3910(97)00151-1.
[5] A. Maleki, J. He, S. Bochani, V. Nosrati, and M. Shahbazi, “Multifunctional Photoactive Hydrogels for Wound Healing Acceleration,” 2021, doi: 10.1021/acsnano.1c08334.
[6] S. Hamedi, “Preparation of antibacterial ZnO NP-containing schizophyllan / bacterial cellulose nanocomposite for wound dressing,” Cellulose, vol. 28, no. 14, pp. 9269–9282, 2022, doi: 10.1007/s10570-021-04119-8.
[7] T. T. Van Nguyen et al., “Synthesis, Characteristics, Oil Adsorption, and Thermal Insulation Performance of Cellulosic Aerogel Derived from Water Hyacinth,” 2021, doi: 10.1021/acsomega.1c03137.
[8] H. Samadian et al., “In vitro and in vivo evaluation of electrospun cellulose acetate/gelatin/hydroxyapatite nanocomposite mats for wound dressing applications,” Artif. Cells, Nanomedicine Biotechnol., vol. 46, no. sup1, pp. 964–974, 2018, doi: 10.1080/21691401.2018.1439842.
[9] H. Türe, “Characterization of hydroxyapatite-containing alginate – gelatin composite films as a potential wound dressing,” Int. J. Biol. Macromol., vol. 123, pp. 878–888, 2019, doi: 10.1016/j.ijbiomac.2018.11.143.