Nanostructuring of Cellulose Using UV Pulsed Laser

Seyoung Kwon[1], Bosung Shin*[2]

1. Cogno-Mechatronics Engineering, Pusan National University

2. Optics and Mechatronics Engineering, Pusan National University

Busan, 609-735, Republic of Korea

** E-mail: bosung@pusan.ac.kr*

ABSTRACT

This study explores using a 355nm UV pulsed laser to create nanocellulose structures by thermally decomposing hydroxypropyl methylcellulose (HPMC) coated on polyethylene (PE) films. The process aims to enhance the tensile strength and permeability of PE films, potentially expanding their applications. Nanocellulose, with its excellent mechanical properties, flexibility, and barrier capabilities, presents a promising alternative to traditional, environmentally challenging production methods.

KEY WORDS

Cellulose, UV pulsed laser, Nanostructuring, Laser fluence

1. INTRODUCTION

Cellulose, a rich, biodegradable, and biocompatible organic compound, is widely used in applications such as paper, fiber, and building materials due to its mechanical strength and stability. With advances in nanotechnology, nanocellulose, an ultra-thin cellulose fiber with excellent mechanical strength, flexibility, transparency, moisture permeability, and gas barrier properties, has been spotlighted as a promising material for high performance composites, medical films, and food packaging.

Traditional methods of producing nanocellulose involve complex chemical or mechanical treatments that are expensive and not environmentally friendly. To address this issue, this study explores the use of UV pulsed lasers, specifically the 355nm UV laser, which enables precise thermal decomposition of cellulose to form nanostructures. In this research, hydroxypropyl methylcellulose(HPMC), a cellulose derivative, was coated onto polyethylene(PE) films and irradiated with a UV laser. This process aims to from nanocellulose structures to enhance the tensile strength and permeability of PE films. The study investigates how these nanostructures can improve the performance of PE films, potentially expanding their application fields.

2. Theory

2.1 Laser Fluence Calculation

The following table presents the specifications of the laser used in this study, and Fig.1 shows a graph of the surface temperature increase of the sample at the center of the laser spot during irradiation.

Table 1: Laser source specification

Parameter	Value	Unit
Wavelength	355	nm
Average Power	5	W
Pulse length	20	ns
Repetition rate	30	kHz
Beam diameter	15	mm

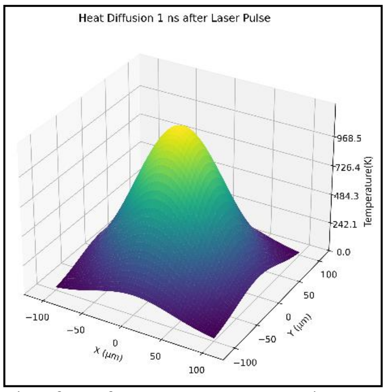

Fig.1: Graph of surface temperature change at laser spot after 1ns

Laser fluence is energy per unit area transferred to the area to which the laser is irradiated and plays an important role in increasing the surface temperature of the irradiated material. The energy absorbed on the surface by the laser pulse generates local heat, leading to a high temperature rise in the center of the laser spot. The initial temperature rise ΔT can be expressed in relation to the absorption rate η, density ρ, and specific heat c of the laser fluence F material, and is defined by the following equation:

$$\Delta T = \frac{\eta \cdot F}{\rho \cdot c} \quad (1)$$

Each variable is explained as follows:

Laser Fluence (F) : Represented in J/cm^2, it denotes the laser energy per unit area and is determined by the laser power and spot size. Higher fluence delivers more energy to the surface, resulting in a greater temperature increase.

Absorption Coefficient(η) : A dimensionless factor

indicating the extent to which the material absorbs the laser energy, which varies depending on the laser wavelength and material properties. Materials with a high absorption coefficient absorb more energy, causing a more substantial temperature rise.
Density(ρ) : The mass per unit volume of the material (kg/m^2), affecting the temperature increase. Higher density disperses the energy, resulting in a reduced temperature rise.
Specific Heat Capacity(c) : The energy required to raise the temperature of a unit mass of the material by 1K (J/kg· K). Materials with a high specific heat capacity exhibit a lower temperature rise for the same amount of absorbed energy.
laser fluence are as follows:

$$F = \frac{E_{pulse}}{A} \qquad (2)$$

Where E_{pulse} is the energy per pulse, and A is the irradiated area of the laser spot(cm^2).
E_{pulse} is calculated as follows:

$$E_{pulse} = \frac{P_{avg}}{f_{pulse}} \qquad (3)$$

where P_{avg} is the laser's average power and pulse frequency f_{pulse}
The temperature rise is highest at the center of the laser spot, with a temperature gradient that decreases radially due to the material's thermal diffusivity α, defined as:

$$\alpha = \frac{k}{\rho \cdot c} \qquad (4)$$

Where k represents the material's thermal conductivity (W/m· K), influencing the rate of heat diffusion within the material. The temperature distribution across the laser spot follows a Gaussian profile, where the temperature decreases as the distance from the spot center increases.

3. Method

The main material used in this study was cellulose, which was dissolved in water and coated on a PE film to proceed with nanostructured process. The Pe film was coated with cellulose dissolved in water at a concentration of 3 wt% using a blade coating technique and filtered at room temperature for 24 hours before nanostructured processing. The cellulose-coated PE film was irradiated with a laser to induce pyrolysis and to form a fine nanostructure on the surface. During laser irradiation, the scan speed and laser output were adjusted to evenly scan the film surface.

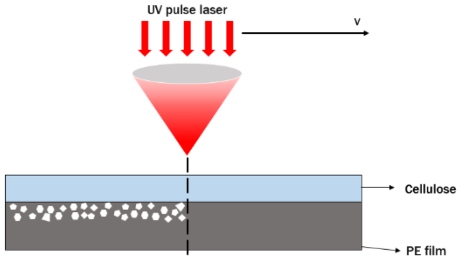

Fig.2 Laser Process

Fig2 shows the laser process. Through laser processing, cellulose molecules are decomposed into nanocellulose and embedded in the PE film.
As a result, a polymer film having biodegradability and excellent air permeability and tensile strength may be manufactured.

REFERENCES

1 Sirviö, Juho Antti, et al. "UV-absorbing cellulose nanocrystals as functional reinforcing fillers in polymer nanocomposite films." Journal of Materials Chemistry A 4.17 (2016): 6368-6375.
2 Kang, Moon Suk, et al. "Fundamental study of direct microporous process using laser shock wave." Applied Physics B 119 (2015): 439-444.
3 Giese, M., and M. Spengler. "Cellulose nanocrystals in nanoarchitectonics-towards photonic functional materials. Mol Syst Des Eng 4: 29–48." 2019,
4 Cheng, Huan, et al. "Multifaceted applications of cellulosic porous materials in environment, energy, and health." Progress in polymer science 106 (2020): 101253.
5 Rodrigues, Pedro V., et al. "Development of a Breathable Packaging Film for Fresh Products." (2024).