A STUDY ON MICRO-PORE FORMATION INDUCED BY LASER PROCESSING IN POLYETHYLENE(PE) FILM WITH CHEMICAL BLOWING AGENT AZODICARBONAMIDE(ADCA)

Chae Yoon Shin[1], Bosung Shin*[1,2]

1. Department of Cogno-Mechatornics Engineering, Pusan National University

2. Department of Optics and Mechatronics Engineering, Pusan National University

Busan, 609-735, Republic of Korea

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

ABSTRACT

In this study, pore formation in polyethylene (PE) film with azodicarbonamide (ADCA) was induced by laser processing. We investigated the process of pore formation by observing the distribution of the pores formed in the film and examining how they varied depending on the beam diameter. A PE film containing 2% ADCA was prepared with 0.02 mm thickness and attached to a copper plate inclining 45 degrees. The number of laser processing was 1, 2, 3, 5, and 10. Pores were observed through an optical microscope, and analyzed according to the number of laser processes. Additionally, the fluence was changed gradually due to the film attached to the diagonal surface, which created diverse pores. The diameter of the pores ranged from 6.73 to 30.43 μm after the laser pulses were applied. This demonstrated that ADCA foamed appropriately depending on the fluence, allowing us to infer the pore formation process.

KEY WORDS

Chemical blowing agent, polyethylene, laser processing, pore formation

1. INTRODUCTION

Porous polymeric films have been widely applied for various industrial purposes. These polymeric films have advantages such as selective permeability, elasticity, stability, and lightweight properties. [1] For food packages, porous films can extend storage of fresh vegetables and fruits, by regulating humidity and concentration of oxygen. [2,3] For filtration purposes, these films function as effective barriers of particulates such as contaminants in water or air systems, while allowing fluid or gas to pass through. [4,5] In the biomedical engineering field, these polymeric films with porous structures can provide improved breathability, supplying adequate oxygen to wound sites while simultaneously protecting them from external contaminants. Additionally, when developed as patch forms with drugs embedded in the porous structure, they enable effective and sustained drug delivery. [7] Given these applications, the development of efficient methods to control the porosity and pore structure of films has become important.

Polyethylene (PE) is a polymer with high-performance for its durability and flexibility and is widely used in industrial products. [8] Azodicarbonamide (ADCA) induces foaming in plastics through thermal decomposition, increasing the porosity. [9-11] By combining PE with ADCA, ADCA acts as a chemical blowing agent forming pores within the PE under thermal decomposition, thereby enhancing the permeability and functionality. [12]

Laser processing, a non-contact technique for precise micro-machining of materials with high accuracy, can facilitate the thermal decomposition of ADCA in PE films, resulting in pore formation with controlled location and size. In this paper, we induced the micro-pore formation within PE film and measured the morphology and distribution of pores under different laser fluence.

2. METHODS

2.1 Laser processing

PE film containing 2% ADCA was fabricated with a thickness of 0.02 mm. The film was fixed at a 45-degree inclined surface, and laser processing was performed using a 450 nm wavelength laser. The laser focus was aligned to the center of the film, and laser scanning was performed from the top to the bottom of the inclined surface. The scanning was set to 1, 2, 3, 5, and 10 times. (see Fig. 1)

2.2 Laser fluence and temperature

To calculate the fluence values that vary across each processed region on the film fixed at a 45-degree inclined surface, the following equation was used. The temperature applied to the film was determined in polar coordinates based on laser irradiation, considering fluence, material constants, and thermal diffusivity. The processed regions of the film were classified into types a, b, c, d, and e. The laser parameters used in this experiment included laser spot diameter, wavelength, pulse frequency, pulse duration, average power, peak power per pulse, and absorption rate. The absorption rate was derived using values for the density, specific heat, thermal conductivity, and thermal diffusivity of ADCA. Using these values, the fluence per pulse and the maximum temperature at the center were theoretically calculated.

2.3 Pore observation

After laser processing, we observed the pores in PE films by optical microscopy, and counted the pores in different sites by using Image J.

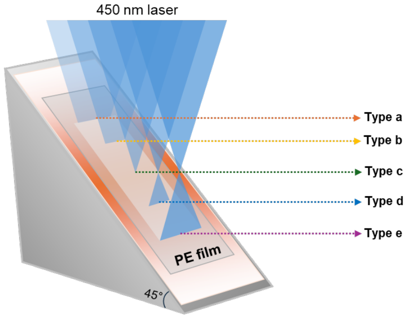

Fig. l. Schematic diagram of laser processing on PE film with ADCA 2%

2.4 Calculation of maximum temperature

In laser processing, energy is delivered very intensively to the surface within a short period, so a 1-dimensional heat conduction equation was used to approximate the general temperature distribution. The parameters include density ρ (kg/m³), specific heat c (J/kg·K), temperature T (K), time t (sec), thermal conductivity k (W/m·K), and heat transfer position x (m).

$$\rho c\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} \quad (1)$$

The laser parameters used in the experiment include spot diameter, laser wavelength, pulse frequency, pulse duration, average power, peak power per pulse, and laser absorptivity. The material properties of the processing material include density, specific heat, thermal conductivity, and thermal diffusivity.

$$T(x,t) = T_0 + \frac{AI_0\tau}{\sqrt{\pi k\rho c}}e^{-\frac{x^2}{4\alpha t}} \quad (2)$$

The center temperature of the laser-irradiated surface can be calculated according to the change in laser spot diameter. A 1-dimensional heat diffusion model was applied to calculate the temperature variation concerning the spot radius on an inclined plane. The density (1.65 g/cm³) and specific heat (1.25 J/g·K) values of ADCA used in the experiment were substituted, but since the thermal conductivity and absorptivity have not yet been measured, generally used values for foaming agents—thermal conductivity (0.1 W/m·K) and absorptivity (0.6). The theoretically predicted maximum temperature by laser spot diameter for ADCA is shown below.

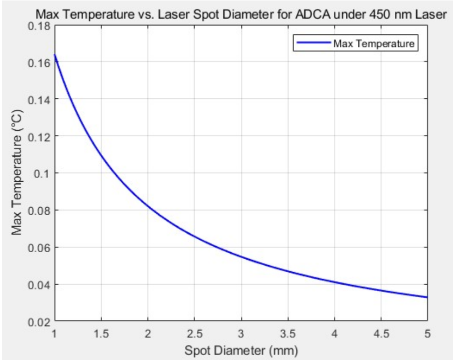

Fig. 2. Maximum temperature by laser spot diameter for ADCA in 450 nm wavelength laser.

REFERENCES

1 Tan, XueMei, and Denis Rodrigue. "A review on porous polymeric membrane preparation. Part II: Production techniques with polyethylene, polydimethylsiloxane, polypropylene, polyimide, and polytetrafluoroethylene." Polymers 11.8 (2019): 1310.

2 Qu, Ping, et al. "Microporous modified atmosphere packaging to extend shelf life of fresh foods: A review." Critical Reviews in Food Science and Nutrition 62.1 (2022): 51-65.

3 Mangaraj, S., T. K. Goswami, and P. V. Mahajan. "Applications of plastic films for modified atmosphere packaging of fruits and vegetables: a review." Food Engineering Reviews 1 (2009): 133-158.

4 Ulbricht, Mathias. "Advanced functional polymer membranes." Polymer 47.7 (2006): 2217-2262.

5 Wang, Mengxue, et al. "Poly (Arylene Ether) s-Based Polymeric Membranes Applied for Water Purification in Harsh Environment Conditions: A Mini-Review." Polymers 15.23 (2023): 4527.

6 Liu, Pei, et al. "Polymer microneedles with interconnected porous structures via a phase inversion route for transdermal medical applications." Journal of Materials Chemistry B 8.10 (2020): 2032-2039.

7 Carey, H., E. F. Schulz, and G. J. Dienes. "Mechanical properties of polyethylene." Industrial & Engineering Chemistry 42.5 (1950): 842-847.

8 Guo, Rui-Lei, Shang-Hao Liu, and Yi-Ming Lu. "Investigation of how pressure influences the thermal decomposition behavior of azodicarbonamide." Journal of Loss Prevention in the Process Industries 83 (2023): 105062.

9 Kmetty, Ákos, Katalin Litauszki, and Dániel Réti. "Characterization of different chemical blowing agents and their applicability to produce poly (lactic acid) foams by extrusion." Applied Sciences 8.10 (2018): 1960.

10 Reyes-Labarta, J. A., and Antonio Marcilla. "Kinetic study of the decompositions involved in the thermal degradation of commercial azodicarbonamide." Journal of applied polymer science 107.1 (2008): 339-346.

11 Robledo-Ortiz, J. R., et al. "Non-isothermal decomposition kinetics of azodicarbonamide in high density polyethylene using a capillary rheometer." Polymer Testing 27.6 (2008): 730-735.