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Effect of hydrothermal temperature on photocatalytic properties of TiO_2 nanotubes

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ABSTRACT

This work presents a study on the effect of hydrothermal temperature and structure on the photocatalytic activity of TiO_2 nanotubes (TNT) prepared using commercially available TiO_2 nanoparticles (P25). From the results, it was found that a higher hydrothermal temperature led to an increase in the specific surface area, total pore volume, and the size of mesopores in TNT. Moreover, the TNTs synthesized by the hydrothermal method had a new structure, which was very different from the anatase and rutile structures found in P25. The TNTs synthesized at 150 °C had the highest specific surface area of 371 m^2/g. However, the TNTs synthesized at 180 °C exhibited the best photocatalytic efficiency and dye adsorption capacity, as compared to other TNTs, resulting from their well-developed mesopores.

1. Introduction

Natural resources of fresh water are being exhausted due to reckless extraction of ground water, environmental pollution promoted by rapid industrial growth, and global warming. Unfortunately, depletion of this magnitude cannot be reversed by natural replenishment cycles of water, especially when factors such as the draining of non-degradable pollutants into water keep increasing due to rapid industrialization. Therefore, environment-friendly water treatment technologies need to be developed to ensure the requisite quantity and quality of water for consumption [1–3]. To that end, several studies have been carried out on semiconductor ceramics, which are able to degrade organic pollutants by a photocatalytic action using light. Among the ceramics, titanium dioxide (TiO_2) is receiving the most attention due to its catalytic efficiency, economics, chemical resistance, and environment-friendliness [4–10].

TiO_2 is non-toxic, insoluble in water, and easy to maintain; In addition, it can self-decompose and it enables a more economical treatment of water than chlorine disinfection [11–14]. In addition, TiO_2 has a strong oxidizing power, and as a photocatalyst, it is certified to be the most suitable catalyst for the degradation of materials presumed to be non-degradable, such as COD, which could not be degraded by existing biological treatment methods [15–18]. Therefore, it is imperative to use this material in challenging environments where industrial wastewater and other organically polluted water are treated [19,20].

TiO_2 nanotubes (TNTs) have recently garnered considerable interest as an effective photocatalyst due to their various advantages promoted by their microstructure, such as a large specific surface area and high pore volume [12–23]. Using techniques, such as hydrothermal synthesis, it is possible to grow TNTs of uniform diameters by using a highly concentrated aqueous solution of NaOH [24,25]. Previous studies have shown that the photocatalytic activity of TNTs can be tuned by controlling their characteristics [26,27], and TNTs can be easily filtered from a solution or degraded by sedimentation because their length spans hundreds of nanometers. Therefore, TNTs can be easily commercialized [28–31].

Previous reports have found that photocatalytic properties occur on the surface of photocatalysts and adsorption of molecules improves the speed of photolysis [32–35]. TNTs are able to adsorb a considerable amount of pollutants because of their large specific surface areas and high pore volumes [36–38], and this adsorption plays an important role in the degradation of those pollutants [39].

Therefore, in this study TNTs were prepared by a hydrothermal synthesis method using a commercially available powder of TiO_2 photocatalyst (P25) and an alkaline solution. The effect of hydrothermal temperatures on the shape of TNTs was analyzed, and it

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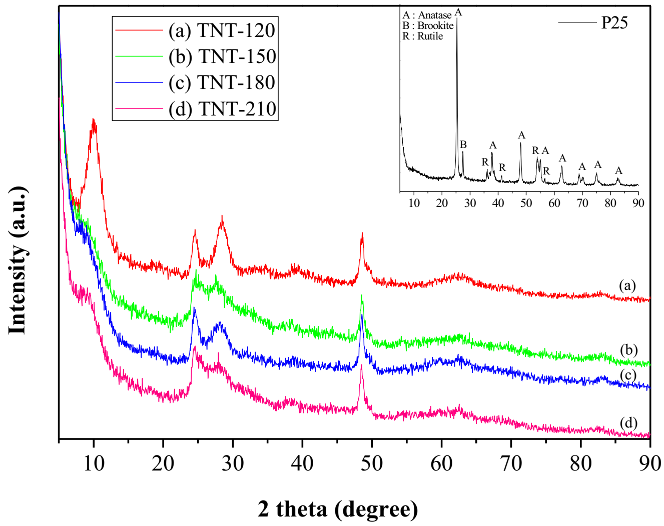

Fig. 1. XRD patterns of P25 and TNTs.

was found that regardless of the conditions, TNTs with a unidirectional structure and high specific surface area were synthesized. In addition, the effect of the structure and morphology of the TNTs on the adsorption and photocatalytic degradation of methylene blue were examined.

2. Experimental

2.1. Materials

TiO_2 powder (P25) was purchased from Degussa, and NaOH of purity 93% was obtained from Duksan to prepare TNTs by the hydrothermal synthesis method. Hydrochloric acid of purity 35% was purchased from Daejung to remove sodium (Na^+) ions, and methylene blue manufactured by Sigma Aldrich was used to test the photocatalytic activity of TNTs.

2.2. Preparation of TiO_2 nanotubes

TNTs were synthesized by the hydrothermal synthesis method using TiO_2 powder (P25) as the starting material and a concentrated solution of NaOH [40–43]. Crystalline TNTs were grown by first adding 5 g of P25 in 50 ml of 10 M NaOH aqueous solution, then stirring the dispersion for 3 h, followed by transferring the dispersion into a Teflon container, and conducting the hydrothermal synthesis at various temperatures between 120 °C and 200 °C in an autoclave. The TiO_2 crystals were collected and washed under

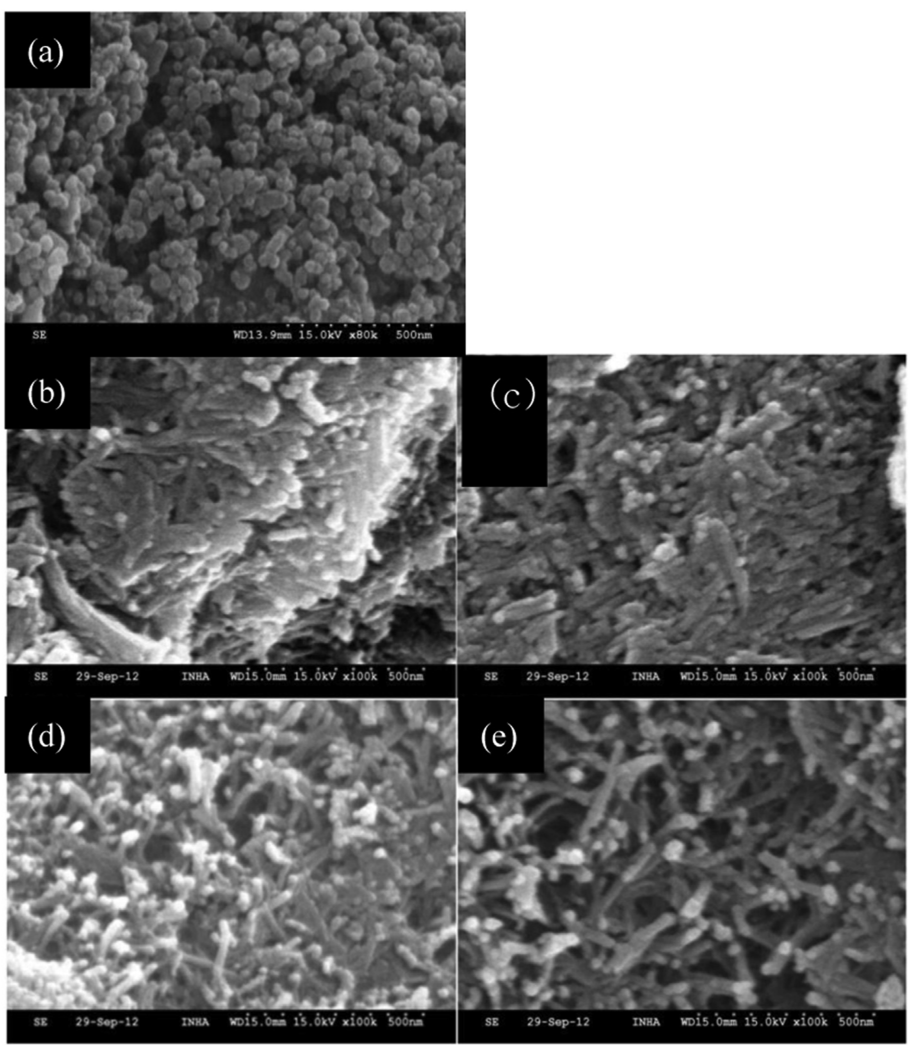

Fig. 2. SEM images of P25 and TNTs; (a) TNT-120, (b) TNT-150, (c) TNT-180, and (d) TNT-210.