Ultraviolet Absorption Capabilities of Iron-Containing Mesoporous Silicas Synthesized by Various Methods

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Abstract

Ultraviolet absorption capabilities of Fe-containing mesoporous silicas (Fe-MPSs) synthesized using different Fe sources, template removal methods, and types of Fe-MPSs were studied. Further, the potential of Fe-MPSs as ultraviolet protecting agents was considered by UV transmittance of thin films of the samples, their color and also photo-catalytic activities. Calcined MCM-41 type Fe-MPS which is synthesized via iron (III) acetylacetone showed the best ultraviolet absorption capability but is slightly brown when Fe/Si mole ratio \( \geq 0.02 \). Contrastingly, both MCM-41 and HMS type Fe-MPS using Fe(acac)₃, as the iron source and removing the template by solvent extraction yielded white powder even though ultraviolet absorption was relatively low. Furthermore, the UV transmittances of thin films of aqueous slurries of the suggested calcined Fe-MPS (Fe/Si mole ratio = 0.02) were equal to that of aqueous slurry of silica surface treated TiO₂. In addition, there was no photocatalytic activity detected in Fe-MPSs synthesized by both suggested methods. These results indicate that Fe-MPSs synthesized by the conditions suggested in this study have the potential for use as new ultraviolet protecting agents.

Key-words: Fe-containing mesoporous silica, Ultraviolet protecting agent, Ultraviolet absorption capability, Photo-catalytic activity

1. Introduction

Ultraviolet radiation (UVR) is one of the causes of skin problems such as sunburn, hyper-pigmentation, and photo-aging1,2,4). It is known that exposure to UVB can cause acute skin erythema and sunburn. On the other hand, UVA can penetrate relatively deep skin layers and may cause DNA damage as well as skin cancer3). Therefore, many specialists recommend applying sunscreen to protect the skin against the harmful effects of UVR2,3,25).

There are two types of sunscreen agents-organic and inorganic. Organic sunscreen agents such as methoxy cinnamate ester and oxybenzone are widely used in sunscreen products. However, there are some concerns about allergic reactions to these agents5). On the other hand, inorganic sunscreen agents such as TiO₂ and ZnO are becoming increasingly popular because of their favorable protection against both UVA and UVB and relative safety. However, inorganic sunscreen agents generally tend to form visible white films on the skin, thus leading to an unnatural appearance6). Furthermore, their particle surfaces are reactive, especially TiO₂, which has strong photo-catalytic properties7,8). Thus far, there have been many attempts to increase their transparency by reducing the particle size9) and to reduce the surface reactivity by coating their surfaces with inert substances10). Nevertheless, difficulties remain in that it is difficult to perfectly coat the particle surface, and an uncoated reactive surface can consequently lead to a shortening of the product shelf life7,8,10).

In order to overcome those drawbacks, a new inorganic sunscreen material is desired that does not show photocatalytic activity and does not form a visible film or cause allergic reactions when applied on the skin. Moreover, in some specific applications, colorless sunscreening agent is required, for example, application into lip glosses or lip cream for which the product colors will be changed if colored agents are used. Mesoporous silica (MPS) is a material formed by a silica framework with pores ranging in sizes from 2 to 50 nm, and it has been researched in various fields such as catalytic chemistry and adsorptive separation because of its high surface area and well-ordered controllable pores. In addition, various heterometal ions can be incorporated into the MPS framework in order to vary the chemical and physical properties. There have been many studies on metal-incorporated MPSs such as Al-16), Fe-13-15), Ti-17), and Zn-containing MPSs18). It is well known that for the transition metal oxide species, the energy of the absorption edge corresponds to the band gap energy (Eg), and the Eg generally changes with the local coordination structure of the species90). In 1984, the data for iron complexes with four, five, and six coordination were reported by Roe et al95). It was reported that the Eg (I) of the Fe oxide is determined by the local coordination of iron and decreases in the following sequence: