Chapter 3
Cellulose-Based Functional Fine Particles and Fibers as Environmentally Friendly Materials:
Development and Application

Shoji Nagaoka
Kumamoto Innovative Development Organization, Japan

Maki Horikawa
Kumamoto Industrial Research Institute, Japan

Tomohiro Shirosaki
Kumamoto Industrial Research Institute, Japan

ABSTRACT

Due to concerns regarding the effect of the large amount of waste accompanying their consumption on the environment, attention has therefore returned to cellulose and to maximize the potential of cellulose. On the development of cellulose refining, combining, and functionalization technologies, this chapter categorizes and introduces the spherical microbeads and nanofiber and then discusses interfacial hydrophilic microbeads, which are used as raw materials for moisturizing cosmetics. In addition, the fabrication of the semiconductor abrasives, thermally conductive materials, abrasive cleaning agents, and three primary color materials for paints are discussed for development of cellulose composite materials with inorganic materials.

INTRODUCTION

Cellulose, a polysaccharide, exists ubiquitously in plants and is an inexhaustible raw material with an annual production far exceeding oil reserves. Since the discovery of cellulose by the French biochemist Anselme Payen in 1838, various techniques for the utilization of cellulose fibers have been developed.

DOI: 10.4018/979-8-3693-0003-9.ch003

Nylon was invented by W. H. Carothers approximately 100 years later (Hermes, 1996). Various petroleum-based synthetic polymers were developed via facile synthetic methods with high production efficiency (Ziegler, 1964; Maddah, 2016; John & Tennant, 1945), following the invention of nylon. These synthetic polymers are commonly utilized for fabricating commodities for daily necessities. Hence, they are produced and consumed in large quantities. The application of cellulose was limited to the manufacture of films, paper, and wood products.

One challenge to utilize celluloses is the processing of cellulose. Its natural form is complex to process as it is resistant to heat, water, or solvents owing to the presence of strong intermolecular hydrogen bonds. Furthermore, the tuning of its reaction is difficult, owing to the three hydroxyl groups in the glucose unit. Conversely, synthetic polymers are easy to process and manufacture with a high production efficiency. Over the years, research on cellulose declined as that on synthetic polymers gained significance.

Synthetic polymers have been produced, consumed, and discarded in large quantities in the 20^{st} century. Mass production of polymers and their waste contributes significantly to global warming due to CO_2 emissions (CO_2 and Greenhouse Gas Emissions website), the depletion of resources (Looney, 2021) and the resulting disasters (Walz et al., 2021). The accumulation of microplastics (MP) pollutes rivers and oceans (Lim, 2021; Bai, et al., 2021; Jambeck, et al., 2015; Xanthos & Walker., 2017), which finally pollute ecosystems through the food chain (Saeedi, 2023). Concepts such as sustainability, sustainable development goals (Brundtland Report, 1987), and carbon neutrality (Carbon Neutral Coalition website, 2023) have been popular in the 21^{st} century as there is a growing awareness on the need to conserve resources. Thus, cellulose-based materials have been gaining renewed attention as alternatives to synthetic polymers. Microcrystalline cellulose (nanocellulose) obtained from wood has been explored as structural or functional materials (Isogai, 2013; Isa et al., 2016; Kondo et al., 2014; Nakagaito & Yano, 2014; Noguchi et al., 2017; Ho et al., 2011). Attempts have been made to replace MP in detergents and cosmetic carriers with environmentally friendly materials, such as cellulose, starch, biodegradable plastics, and silica, to reduce river and ocean pollution (Ministry of the Environmental website, Japanese government; *2020 Current status and future prospects of the fine powder market*, Market research report).

In this chapter, we describe the development of two cellulose-based materials: spherical microbeads and functional nanofibers. We first discuss the development of cellulose spherical microbeads (CSM) packings for liquid chromatography separation (Motozato et al., 1981, 1984; Nagaoka et al., 1994; Hirayama et al., 1995). Next, we explain the development of spherical microbead composites fabricated using cellulose and inorganic materials. The developed composites were used as semiconductor abrasives (Nagaoka et al., 2008), three primary colorants in paints (Nagaoka et al., 2001, 2005a, 2007), and heat-dissipating materials. Skin moisturizers using surface-hydrophilized cellulose microbeads with a focus on MP were also developed.

Composites using conductive polymers have also been fabricated using nanofibers. We have succeeded in increasing the conductivity of a resin (Horikawa et al., 2015, 2018, 2017, 2020) and used it as a heat-shield material absorbing near-infrared (NIR) rays (Yoshida et al., 2020). The developed material was incorporated into a sash that could be used as a heat-insulating interlayer for windows. The performance was verified and the ability of the material to control CO_2 emissions and save energy was confirmed. The practical application of the fabricated composites is also reported.