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Electrorheological properties of algae dispersed suspension: New application of harmful algae

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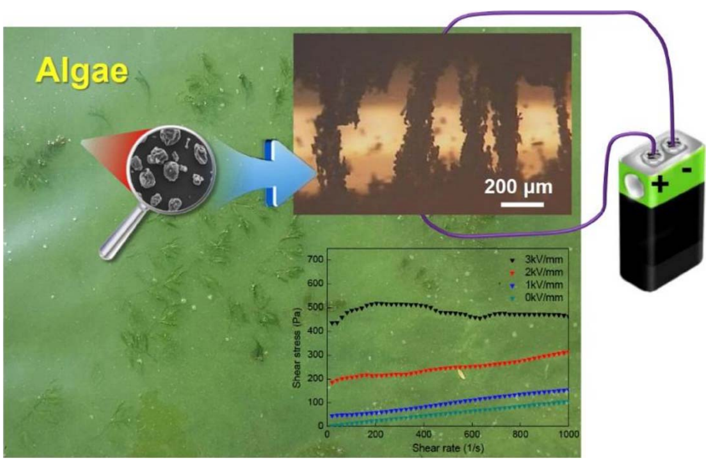
GRAPHICAL ABSTRACT



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ABSTRACT

The algae has been considered as a bane which should be removed due to its harmful influences on human health and aquatic ecosystems. Recently, various applications of the algae have been studied as a new alternative method instead of its sequestration, to treat vast algae blooms. Herein, algae particles dispersed suspensions have been investigated as a promising new application to electrorheological fluids without any further processing, such as chemical modification, extraction and carbonation. Algae particles dispersed silicone-oil suspensions exhibited good electrorheological properties under DC electric fields, and their electrorheological performances were enhanced with increase of electric fields. The alignment of algae particles along DC electric fields in the suspension, that inhibits the suspension flow by the drag of the dangling alignments and consequently increases the viscosity of the suspension, was observed under the electric fields. The ER properties of algae particles dispersed suspensions were same with (or similar to) those of cellulose phosphate dispersed suspension (yield stress: ca. 400 Pa at 3 kV/mm; polarizability, $\Delta\varepsilon$: ca. 0.35) owing to the phosphate groups in

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the algae particles. Our research has demonstrated that the electrorheolgical fluids is very promising for the ecofriendly application of the mass-producing algae particles.

1. Introduction

Overgrowth of algae caused by lake eutrophication has led an environmental problem seriously around the world. Various toxins contained in tainted drinking water by harmful algae blooms (HABs) threaten the health of the people ranging from acute pneumonia to mild skin irritation and gastroenteritis [1]. Floating non-toxic algae on the surface of lake also has destroyed aquatic ecosystems by causing anoxia-the lack of oxygen [2].

Thus, to lessen the outbreak and incidence of HABs, various researches have been performed by several techniques, such as adsorption [3,4] (reduce of nutrients causing lake eutrophication), flocculation [5] (sedimentation of floating algal bloom) and cell lysis [6] (phylogenetic regression). In spite of various researches, HABs have not been readily reduced due to their vast supply attributed to proliferation and growth conditions with harnessing sunlight and CO_2 [7]. However, the case of algae in the surface ocean is different. It is in charge of about half of all the global photosynthetic activity which sequestrates CO_2 from the atmosphere [8]. Recently, an application of algae to biosorption materials [9], electrode [10] and production of bioenergy/biofuels [11] have been studied as a new alternative method to treat vast algae blooms. For the application of HABs to various materials, further processes are required such as chemical modification, extraction, carbonation, etc. These processes also lead environmental pollutions by organic solvents, metal powders, and burning of fossil fuels causing the CO_2 emission [12]. Therefore, the research for application of pristine HABs to useful materials has been required for their completely ecofriendly applications.

Electrorheological (ER) fluids consisting of an insulating liquid medium and a polarizable particulate/liquid material are smart fluids whose rheological properties are readily controllable reversibly under an electric field [13]. Because of their various applications such as shock absorbers [14], vibration dampers [15], aritificial muscle simulators [16], microfluidic pumps [17], microvalves [18], etc., numerous materials such as TiO_2 [19], graphene oxide [20] and synthetic polymers [21,22] have been tried as polarizable particulate materials to enhance the ER performance. Natural polymers, such as chitosan/chitin [23,24], starch [25,26,27], cellulose [28,29]. and alginate [30] have emerged for ER materials owing to various merits of abundant supply, readily chemical modification, biocompatibility and biodegradation [23]. Algae, consisting of various polysaccharide, can be regarded as one of natural polymers [31].

Herein, the potential of algae powders as ER materials have been demonstrated to enhance the use of the powders without additional processes. Our group and other research groups have exhibited that the modification of natural polymers with phosphate groups is easy method to prepare the ecofriendly ER particulate materials for enhancing ER performances [32,33]. Chemical compositions of algae on a dry matter are carbohydrates, proteins, lipids and nucleic acids [34]. Phosphate groups exist in the compositions [35]. Thus, the effect of phosphate groups to enhance ER performances can be expected without further modification process when algae powders are used for ER particulate materials. To demonstrate ER effects of algae powders, *Chlorella vulgaris* (*C. vulgaris*), *Nannochloropsis gaditana* (*N. gaditana*) and *Chlorella pyrenoidosa* (*C. pyrenoidosa*) powders were used for ER particulate materials, and cellulose and cellulose phosphate were examined for comparison with them. Chemical compositions of the algae powders, cellulose powder and cellulose phosphate powder were characterized by Fourier transform infrared (FT-IR) spectroscopy, X-ray photoelectron spectroscopy (XPS), energy-dispersive X-ray spectroscopy and time-of-flight secondary ion mass spectroscopy (TOF-SIMS). The electrorheological and electrical properties of the powders dispersed fluids were investigated under DC electric fields. All of the algae powders dispersed fluids showed noteworthy ER performances, and one of the most noticeable results is the yield stress of the *C. pyrenoidosa* powder dispersed fluid (435.5 Pa) is higher than that of the cellulose phosphate powder dispersed fluid (391.5 Pa) at 3 kV/mm. Obtained experimental results have demonstrated that harmful algae powders can be a new and ecofriendly material exhibiting ER properties without any further modification.

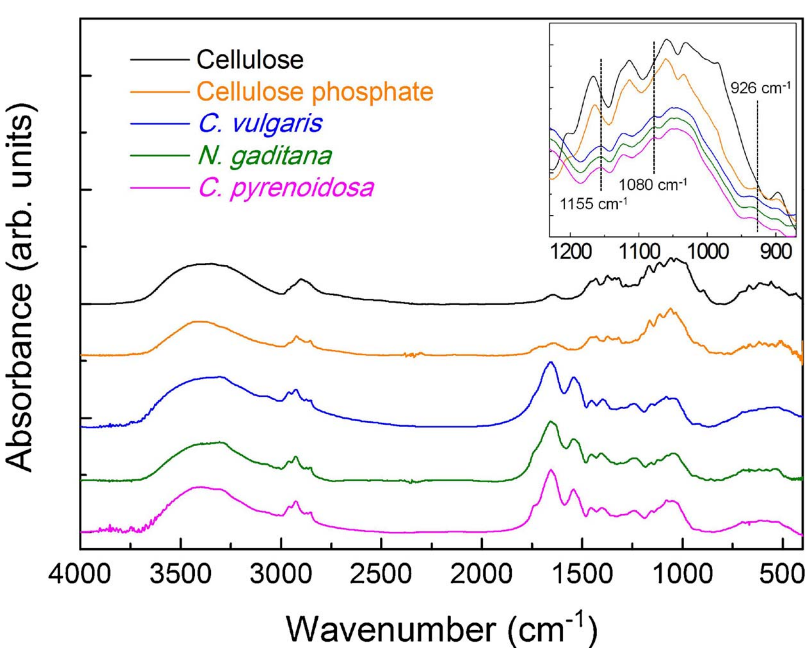

Fig. 1. FT-IR spectra of cellulose, cellulose phosphate, *C. vulgaris*, *N. gaditana* and *C. pyrenoidosa*.