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Characterization of field-induced needle-like structures in ionic and water-based magnetic fluids

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Abstract

An attempt has been made to characterize the field-induced needle-like structures (secondary cluster SC) in ionic and water-based magnetic fluids (MFs) using Rayleigh light scattering technique. This technique has the advantage of detecting objects smaller than the resolution limit of the optical column. From the observations, it was found that though water is the solvent in both ionic and water-based magnetic fluids, the cluster characteristics under zero and applied magnetic field, their growth and disintegration were different. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Primary cluster; SC; Ionic MF; Water-based MF; Ultramicroscope

1. Introduction

In non-polar or polar solvent-based MF, the particles are coated with single or double layers of surfactants. In the case of oil-based MF [1], the particles are coated with a single layer of surfactant. On the other hand, the magnetite particle dispersion in water is ensured in two different ways: (a) steric repulsion with double layers of surfactants [2] or (b) screened electrostatic interaction using low polarizing counter-ions of tetramethylammonium (TMA) (ionic MF) [3]. It has been inferred by researchers that the ferromagnetic particles in some MFs form needle-like structures stretched in the direction of the magnetic field. Recently, Nakatani [4] reported the presence of clusters (primary) even under zero applied field in water-based MF and extreme differences in the characteristics of the field-induced needle-like structures (SCs) between water and oil-based MFs. In this paper, we study the SC formations in ionic MF, and the influence of the solid fraction content and magnetic field strength on their characteristics and compare with water-based MF.

2. Experimental

Ultramicroscope set up used is described elsewhere [4]. The MFs W40 (water based) is a product of Taiho Co. Ltd., Japan. Ionic MF (IFF20) was prepared as given in Ref. [5]. Homogeneous DC

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magnetic field of maximum 0.05 T was applied parallel to the plane of the sample cell using an electromagnet. Samples with solid fractions 1, 5 and 10% of IFF20 and W40 were prepared by diluting each of the original MF with aqueous solution of TMA and aqueous solution of sodium dodecyl benzene sulfonate, respectively.

3. Results and discussion

3.1. Primary clusters

In the ultramicroscope, the presence of any object is visualized due to Rayleigh scattering of light by the object and the detectable limit depends on the scattering intensity. Here, the light scattering intensity mainly depends on particle diameter. We could observe some basic differences among the two types of MF: water-based (W40) and ionic (IFF20) MFs, under zero applied field. As reported earlier [4], in the water-based MF, we observed extremely large number of agglomerated magnetic particles (primary clusters) that scatter specks of light even under zero applied field. The scattered light intensity show a variation with time suggesting rotation of the non-spherical object. The ionic MF, however, does not show any specks, or show a small number of specks of light. It is believed that the method of synthesis of water-based MF holds the key for the presence of primary clusters even in zero applied field. Here, the magnetite particles are initially adsorbed with oleate where, hydrophilic end of oleate chemisorbs on the particle surface and the hydrophobic end face the solvent water. Thus, the particles do not acclimatize themselves with surrounding and begin to coagulate. Thereafter, the SDBS that physisorbs as the second layer is added only to these aggregates. Though some of them disperse in water as individual particles fairly large percent of them remain as aggregates.

3.2. Secondary clusters

When an external field was applied parallel to the plane of the sample cell, SCs that have a needle-like structure stretched in the magnetic field direction [4]. In water-based MF, the SCs were formed mostly through an arrangement of the primary clusters. And, in the case of ionic MF SCs formed from the background that contained invisible particles or particle aggregation. However, the light scattering behavior of needle-like structures in water-based and ionic MF was similar. Fig. 1 shows the ultramicroscope images of SCs observed in different densities of ionic MF. The average length of the clusters formed was a few microns long when the solid fraction content was 1% and reaches up to several hundreds microns for the solid fraction content of 10%. While in the case of water-based MF, the average lengths of the SCs formed became small when the solid concentration

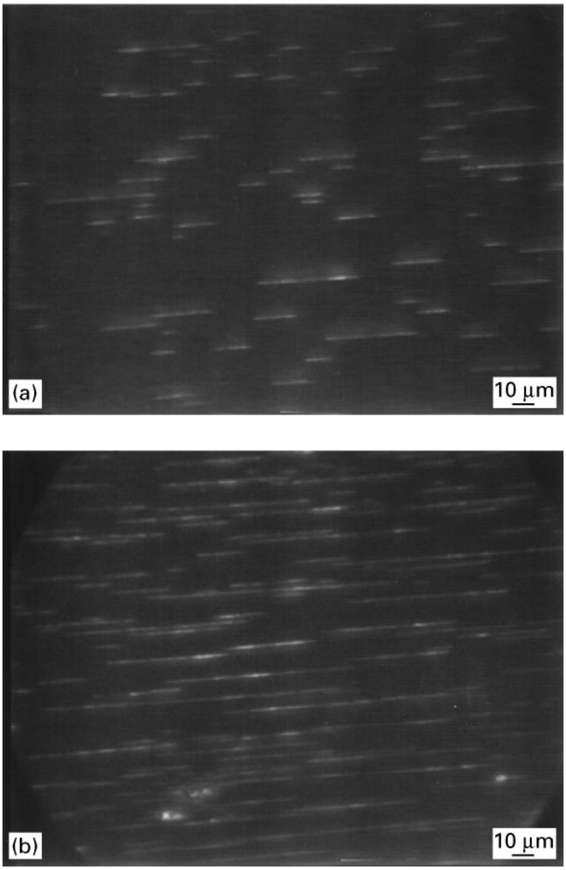

Fig. 1. Ultramicroscope images of SCs formed 120 s after applying 0.05 T in ionic MF with solid fraction content of (a) 5 wt% and (b) 10 wt%.

was increased from 5 to 10%. The size and behavior of the SCs in both types of MF at maximum concentration is an area to be studied. Furthermore, it was observed that the cluster length increased with the strength of the applied field.

3.3. Growth process

Growth of SCs in MF was studied by applying a magnetic field of 0.05 T for 160 s, a period which was long enough for the system to reach equilibrium. The concentration of the MF considered for the analysis was 10%. The SC growth behaviors were different between MFs. In water-based MF, the primary clusters soon arranged themselves to form the SCs having lengths of up to about 10 μm in 17 s and reached to about 70 μm after 160 s. However, the ionic MF SCs grew to the maximum length of 100 μm after exposing to the magnetic field for 17 s as shown in Fig. 2a. In the course of time the clusters grew as long as 200 μm in size as shown in Fig. 2b. It is believed that one of the reasons for the difference in growth process among MF is the difference in the size and population of the primary clusters. However, the above difference alone is insufficient to explain the observation and it demands further investigation.

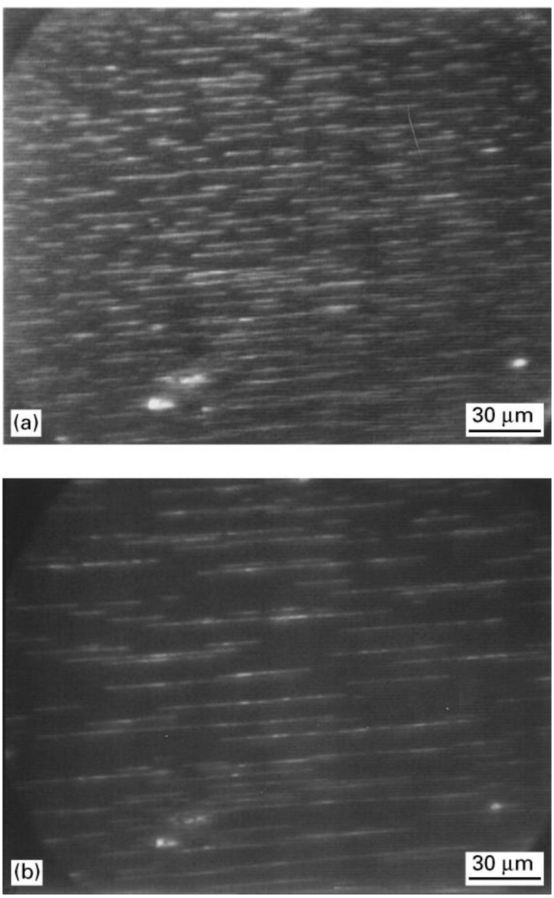

Fig. 2. Ultramicroscope images of SCs formed within (a) 17 s and (b) 165 s under 0.05 T in ionic MF with a solid concentration of 10%.

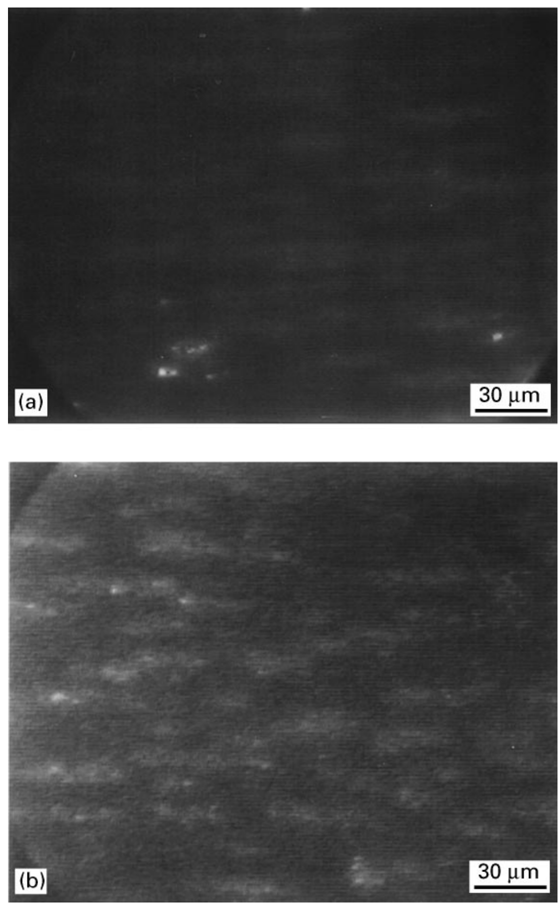

Fig. 3. Ultramicroscope images of disintegrating SCs, 3 s after removal of the field in (a) ionic and (b) water-based MF of 10 wt%.

3.4. Disintegration process

Disintegration process of the clusters grown for 160 s under an applied field of 0.05 T was also studied. The SCs formed in kerosene-based MF disintegrated within a fraction of a second and no primary clusters large enough to scatter light within the detectable limit was present. On the other hand, the water-based as well as ionic-based MFs took time in the order of few seconds to disintegrate. During disintegration of ionic MF, the SC images faded away like a cloud as shown in Fig. 3a, whereas, in water-based MF, SCs broke away into specks of light as shown in Fig. 3b and large number of them remained visible for indefinite time.

4. Conclusions

From qualitative and quantitative observation of field-induced needle-like structures in ionic and water-based MFs, we conclude the following: (a) primary clusters large enough to scatter light are found only in water-based MF. However, the light scattering behavior of SCs in ionic and water-based MFs looked alike. (b) Length of SCs increased with the strength of magnetic field. (c) Average length of SCs formed for a given solid concentration and applied magnetic field strength in ionic MF was longer than water-based MF. (d) Average length of the SCs in water-based MF reduced when the solid concentration was increased from 5 to 10%.

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