OS5-5

宇宙実験で生成した荷電コロイド粒子の集合体構造の解析

Analysis of the Aggregate Structure of Charged Colloidal Particles Obtained From Space Experiments

土井 眞帆 [1],三木 裕之 [2], 豊玉 彰子 [2], 奥薗 透 [2], ○山中 淳平 [2], 足立 聡 [3], 坂下 哲也 [3], 島岡 太郎 [4], 永井 正恵 [4], 渡邊 勇基 [5], 福山 誠二郎 [5]

Maho DOI[1], Hiroyuki MIKI[2], Akiko TOYOTAMA[2], Tohru OKUZONO[2], Junpei YAMANAKA[2], Satoshi ADACHI[3], Tetsuya SAKASHITA[3], Taro SHIMAOKA[4], Masae NAGAI[4], Yuki WATANABE[5], and Seijiro FUKUYAMA[5]

1 名市大薬, Faculty of Pharmaceutical Sciences, Nagoya City Univ.
2 名市大院薬, Graduate School of Pharmaceutical Sciences, Nagoya City Univ.
3 宇宙航空研究開発機構, Japan Aerospace Exploration Agency
4 一般財団法人 日本宇宙フォーラム, Japan Space Forum
5 株式会社 エイ・イー・エス, Advanced Engineering Services Co., Ltd.

1. Introduction

Cluster formation of submicron to micron-sized materials is observed in a variety of phenomena, including the crystallization process of colloids and protein aggregation. One of the main driving forces of such cluster formation is the electrostatic attraction between charged particles[1-3]. We are investigating the control of clustering by tuning the electrostatic interparticle interactions of variously charged colloids formed in aqueous media. **Figure 1** shows an example of positively (red) and negatively (green) charged colloidal clusters in water. The sample is fixed in a polymer gel for observation. Micrometer-sized clusters of colloidal particles are promising structures for optical material applications, which often require colloidal particles with a high refractive index (n_r). However, materials with high refractive indexes have, at the same time, high specific gravity. In July 2020, a cluster formation experiment (JAXA Colloidal Clusters) [4] was conducted in the microgravity environment of the International Space Station "Kibo" module. In March 2021, the experiment was returned to the ground, and analysis was started. In this report, we present the results of the structural analysis by image processing.

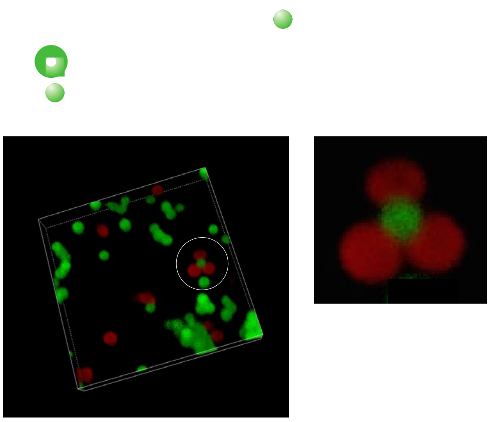

Figure 1 Schematic diagram of the aggregation of positively and negatively charged colloidal particles and an example of microscopic images.

2. Space experiment

A plastic bag composed of two rooms (3 mL each) connected by a breakable separator was employed for the experiments (**Figure 2**). Aqueous dispersions of charged polystyrene (n_r = 1.60; specific gravity d = 1.05), silica (n_r = 1.45; d = 2.1), and titania (TiO_2, n_r = 2.5; d = 3) were used as colloid samples. The surfaces of the silica and titania particles were given surface charges by introducing a positively and negatively charged polyelectrolyte; **Figure 3** shows a schematic of the positive and negative titania particles and an electron micrograph of the core titania particles.

Figure 2 Sample bag used in the space experiment; two bags (3 mL) are connected by a bulkhead, and the two liquids are mixed by crushing the whole bag. The sample is set in a device equipped with a UV-LED and gelatinized by UV irradiation.

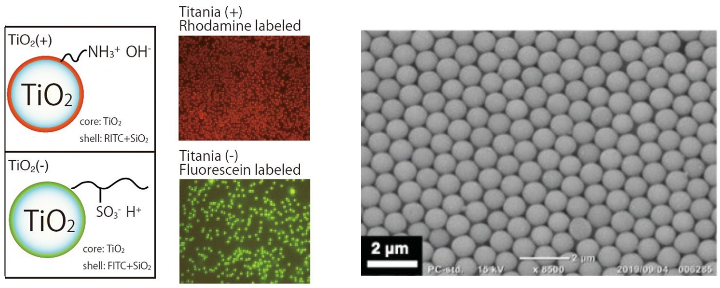

Figure 3 Schematic of positively and negatively charged titania particles. The core titania particles are coated with a silica layer, and the surface is modified with a polyelectrolyte to introduce a charge. The silica-coated layer is colored with red and green fluorescent dyes.

Dilute dispersions of positively and negatively charged colloidal particles (about 0.01 vol% in total) were introduced into two plastic bags, and the two dispersions were mixed by the space crew pushing the bags in the microgravity environment of the ISS. The samples were dissolved with a UV-curing gelling reagent. After mixing, the samples were left in microgravity for 2 days and irradiated with UV light using a UV-LED to immobilize them in polymer gels. All returned samples were gel-fixed, and there was no clear supernatant area due to precipitation, indicating that the particles were uniformly dispersed.

Microscopic examination of the polystyrene samples showed that clusters of positively and negatively charged particles were formed with various numbers of associations, including tetrahedral clusters. The average number of clusters was larger and more regular for the space sample, despite the small difference in specific gravity between the particles and the medium (0.05). Details of the analysis of the polystyrene system will be reported in the poster session.

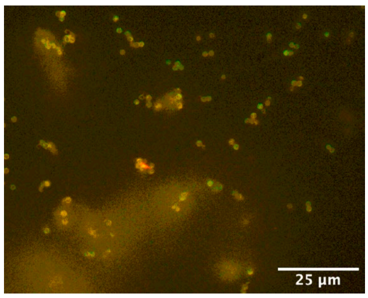

Figure 4 Titania-based clusters generated in the space experiment.

Figure 4 is an optical micrograph of titania clusters generated in the space sample. The magnitude of the electrostatic interaction between the particles is stronger for higher charge numbers, and weaker for higher salt concentrations due to electrostatic shielding by ions. The number of clusters consisting of one positive and one negative particle was measured for samples of various salt concentrations and charge numbers, and it was found that the number of aggregates increased with lower salt concentrations and higher charge numbers. Thus, for the

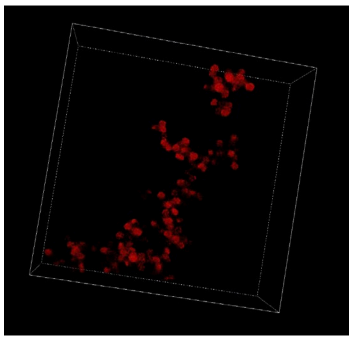

Figure 5 Macroscopic aggregate structure of titania systems generated in space experiments.

first time, aggregates of titania particles, which are difficult to analyze on the ground due to sedimentation, were obtained in a space experiment. The significant effect of electrostatic interaction on the clusters of titania particles was experimentally confirmed.

The fractal dimension d_f of macroscopic aggregates of titania particles was obtained by microscopic observation; **Figure 5** shows an example of a micrograph of an aggregate. The high specific gravity titania particles form dense agglomerates with d_f close to $d_f = 3$ on the ground, due to significant gravitational settling. The bulky agglomerates with $d_f = 2$ were observed in the microgravity environment, where the sedimentation effect is negligible.

3. Conclusions

We reported the structural analysis of colloidal clusters and aggregates produced in the JAXAColloidal Clusters space experiment. In the polystyrene particle system, the average number of aggregates was larger and the regularity was better in the space sample, despite the small difference in specific gravity between the particles and the medium (0.05). In the titania system, the large specific gravity difference (~2) causes macroscopic precipitation on the ground, but microgravity allowed us to confirm the influence of electrostatic interactions on clustering and aggregation. The effect of microgravity on the fractal dimension of aggregates was also confirmed.

References

1) N. B. Schade *et al.*, *Phys. Rev. Lett.*, **110**, (2013),148303.
2) Y. Nakamura *et al.*, *Langmuir*, **31**, (2015) , 13303.
3) T. Okuzono *et al.*, *Phys. Rev. E*, **94**, (2016) 012609.
4) JAXA Web page, https://humans-in-space.jaxa.jp/kibouser/subject/science/70504.html