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A lunar dust simulant: CLDS-i

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Abstract

Lunar dust can make serious damage to the spacecrafts, space suits, and health of astronauts, which is one of the most important problems faced in lunar exploration. In the case of rare lunar dust sample, CLDS-i with high similarity to the real lunar dust is an important objective for studying dust protection and dust toxicity. The CLDS-i developed by the Institute of Geochemistry Chinese Academy Sciences contains ~75 vol% glass and a little nanophase metal iron (np-Fe^0), and with a median particle size about 500 nm. The CLDS-i particles also have complicated shape and sharp edges. These properties are similar to those of lunar dust, and make the CLDS-i can be applied to many fields such as the scientific researches, the treatment technology and toxicological study of lunar dust.

Keywords: CLDS-i; Lunar dust simulant; np-Fe^0; Properties

1. Introduction

Since the Apollo era, it is known that the dust on lunar surface can cause serious problems for lunar exploration activities. Such problems could be sorted into nine categories: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation (Gaier, 2005; Stubbs et al., 2007; Khan-Mayberry, 2008; Cain, 2010). Recently, the mechanical failure encountered by Chinese Yutu lunar rover after the first lunar night might be caused by lunar dust as speculate. To mitigate the effects of the lunar dust, it is necessary to carry out systematic researches as soon as possible.

Lunar dust is the <20 μm fraction of the lunar soil (definition adopted by Lunar Airborne Dust Toxicity Analyses Group, LADTAG), and more than 95% is less than 2 μm in diameter. Their main particle size is about 100–300 nm (Liu and Taylor, 2008; Park et al., 2008; Taylor et al., 2009). It is formed by space weathering processes involving the continuous bombardments by meteorites and micrometeorites, as well as solar wind and galactic/cosmic ray particles (Taylor et al., 2001a). The properties of lunar dust including chemistry and mineralogy, particle size, and morphology are distinguished from those of lunar soil. According to the investigation of Lunar Soil Characterization Consortium (LSCC), the bulk chemistry of lunar dust shows little change in SiO_2 content, but is rich in plagioclase component ($Al_2O_3 + CaO$) and decreases in mafic component ($FeO + MgO$) (Taylor et al., 2001b; Wallace et al., 2009). It mainly consists of agglutinitic glass, plagioclase, pyroxene, along with less ilmenite and olivine. The abundance of agglutinitic glass in most lunar dust is

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generally more than 50 vol%, and the <10 μm fraction contains up to 70 vol% (Taylor et al., 2003; Liu and Taylor, 2011). Np-Fe^0 grains produced by space weathering have been widely observed in the lunar dust particles (Hapke et al., 1975). The np-Fe^0 grains in the amorphous rims around the lunar dust particles surfaces are produced from vapor deposition by micrometeorites bombardments and sputtering deposition by solar wind. And their particle size ranges from several nanometers to tens of nanometers (Keller and McKay, 1993). The particle shape of lunar dust is complexity and has usually sharp edges (Liu et al., 2008). The unique physical and chemical properties of lunar dust have a great impact on lunar exploration, and might make a significant effect on the performance of spacecrafts and the health of astronauts.

With the development of lunar exploration, a great deal of lunar dust samples would be needed both in many engineering tests and scientific researches. But lunar dust sample is too scarce to meet these needs. A feasible approach is developing a lunar dust simulant to substitute the real lunar dust in engineering tests and scientific researches. The properties of CLDS-i lunar dust simulant developed by the Institute of Geochemistry Chinese Academy show a higher similarity to those of lunar dust. The mean grain size of CLDS-i is about 500 nm, and with complicated shape and sharp edges. Besides, it contains np-Fe^0 grains. Therefore, CLDS-i can be applied to many fields such as the scientific researches, the treatment technology and toxicological study of lunar dust.

2. Sample development

According to the basic characteristics of lunar dust, we consider chemistry, mineralogy, particle size and morphology, and np-Fe^0 grains as standards in developing the CLDS-i. Firstly, the CLRS-1 lunar soil simulant (i.e. CAS-1) (Zheng et al., 2009) is ground preliminarily and then separated into two parts of strong and weak magnetism by Magnetic Separation in magnetic intensity with 16,000 T. The part of weak magnetism mainly consists of glass and plagioclase, which is similar to those of lunar dust. Secondly, the part of weak magnetism is ground to submicron size by Planetary Ball Mill PM 100. In order to avoid contamination, the optimal proportion of feed material, zirconium oxide grinding balls and anhydrous alcohol are chosen. The sample after ground then further broken using ultrasonic crusher. A loose powder sample can be obtained after freeze-drying. Thirdly, the powder is coated with an amorphous silicate layer embedded with np-Fe^0 grains by laser bombarding to basalt and metallic iron targets successively in low pressure and nitrogen protective environment. The pulse laser irradiation is used to be comparable with the micrometeorite impacts (Yamada et al., 1999), which can make the target material deposition to the sample particles surfaces. At last, the CLDS-i is produced, which is similar to the real lunar dust in chemistry, mineralogy, grain size and morphology, and np-Fe^0 grains (Fig. 1).

Fig. 1. The appearance of CLDS-i.

3. Properties of CLDS-i

3.1. Mineralogy

To investigate the mineralogy of CLDS-i, the X-ray Powder Diffraction (XRD) and Transmission Electron Microscope (TEM) with Electron Diffraction (ED) and Energy Disperse Spectroscopy (EDS) have been used. The XRD pattern shows that the CLDS-i lunar dust simulant mainly consists of glass and plagioclase, with less olivine, pyroxene and ilmenite. With the TEM, 500 particles of CLDS-i have been examined statistically. In the experiment, electron diffraction pattern could be used to distinguish whether the grain is crystal, and the chemical composition obtained by EDS could be used to determine the mineral type of grains. The results reveal CLDS-i contains ∼75 vol% of glass and ∼15 vol% of plagioclase, as well as ∼10 vol% of olivine, pyroxene and ilmenite. So, the mineral composition of CLDS-i is similar to those of lunar dust.

3.2. Bulk chemistry

The results of X-ray Fluorescence (XRF) show the bulk chemistry of the CLDS-i contains ∼50 wt% SiO_2, ∼14 wt% Al_2O_3, ∼12 wt% TFeO, ∼9 wt% MgO and ∼7 wt% CaO, which is close to that of Apollo low-Ti lunar mare dust (Table 1). The content of the CaO is relatively low, because the albite is primary in Earth while anorthite is primary in Moon.

3.3. Particle size and morphology

With the Laser Particle Size Analyzer, the particle size distributions (PSDs) of CLDS-i have been measured (Fig. 2). Most of them are smaller than 1 μm, and the mean particle size is about 500 nm. It is slightly larger than those

Table 1
The bulk chemistry of Apollo 15, CLRS-1, and CLDS-i.

	15041		CLRS-1	CLDS-i
	10–20 μm	<10 μm		
SiO_2	46.20	46.60	49.24	49.99
Al_2O_3	13.50	16.40	15.80	14.09
MgO	10.80	9.37	8.72	8.16
CaO	10.20	11.60	7.25	7.17
MnO	0.21	0.17	0.14	0.11
FeO or TFeO	14.40	11.00	11.47	11.53
Na_2O	0.41	0.49	3.08	2.78
K_2O	0.18	0.23	1.03	1.23
TiO_2	1.88	1.79	1.91	1.22
Total	97.78	97.65	98.64	96.28

Notes: The data of 15041 is from Taylor et al. (2001a); and the data of CLRS-1 is from Zheng et al. (2009).

of lunar dust. Compared to the mean particle size of JSC-1Avf, CLDS-i is nearly close to the real one (Park et al., 2008).

The images of Scanning Electron Microscopy (SEM) show the morphology of CLDS-i is complicated and the particles usually have sharp edges (Fig. 3). The statistical results show the particles of CLDS-i have a mean length of long axis about 0.444 μm and short axis about 0.327 μm. The proportion of the particles with roundness <0.5 is about 72.4%. To describe the complexity of the particle, a complexity factor is defined as the ratio of measured perimeter to the perimeter of a fitted ellipse (Liu et al., 2008). With the statistical results, the average complexity factor of CLDS-i is about 1.38. The complexity factor of most lunar dust is >1.25. However the complexity distribution of the <1 μm and >1 μm fractions of JSC-1Avf centers at 1.1–1.2. The sharp edges and complicated shape make the CLDS-i very similar to those of lunar dust.

3.4. Np-Fe^0 grains

Np-Fe^0 is pervasive in lunar dust particle, especially in the finest part. And the High-Resolution Transmission Electron Microscope (HRTEM) has been used to check whether there are any np-Fe^0 grains in CLDS-i particles. With the high resolution images of HRTEM, the distance of lattice plane could be measured. By comparing the value to the lattice plane distance of metal iron, the mini-particle could be determined whether it is the metal iron. The microstructure of the CLDS-i particle has been analyzed carefully with HRTEM. The results indicate that there is an amorphous layer covered on most of the particles surfaces, and some nanometer scale crystals embedded in the layer. These nanometer scale crystals usually show spherical shape with the particle size is about 3–10 nm (Fig. 4a). By measuring the distance of lattice plane, the value of 0.204 nm has been obtained (Fig. 4b). It is consistent with the lattice plane distance (0.203 nm) of α-Fe (bcc) (Thompson et al., 2015). It could indicate that those nanometer scale crystals embedded in the amorphous layer are nanophase α-Fe^0. JSC-1Avf does not contain any nanophase iron, whereas CLDS-i with np-Fe^0 grains is close to lunar dust.

4. Conclusions and prospectives

Harmfulness of lunar dust is considered to be a big problem in future lunar exploration. In order to mitigate

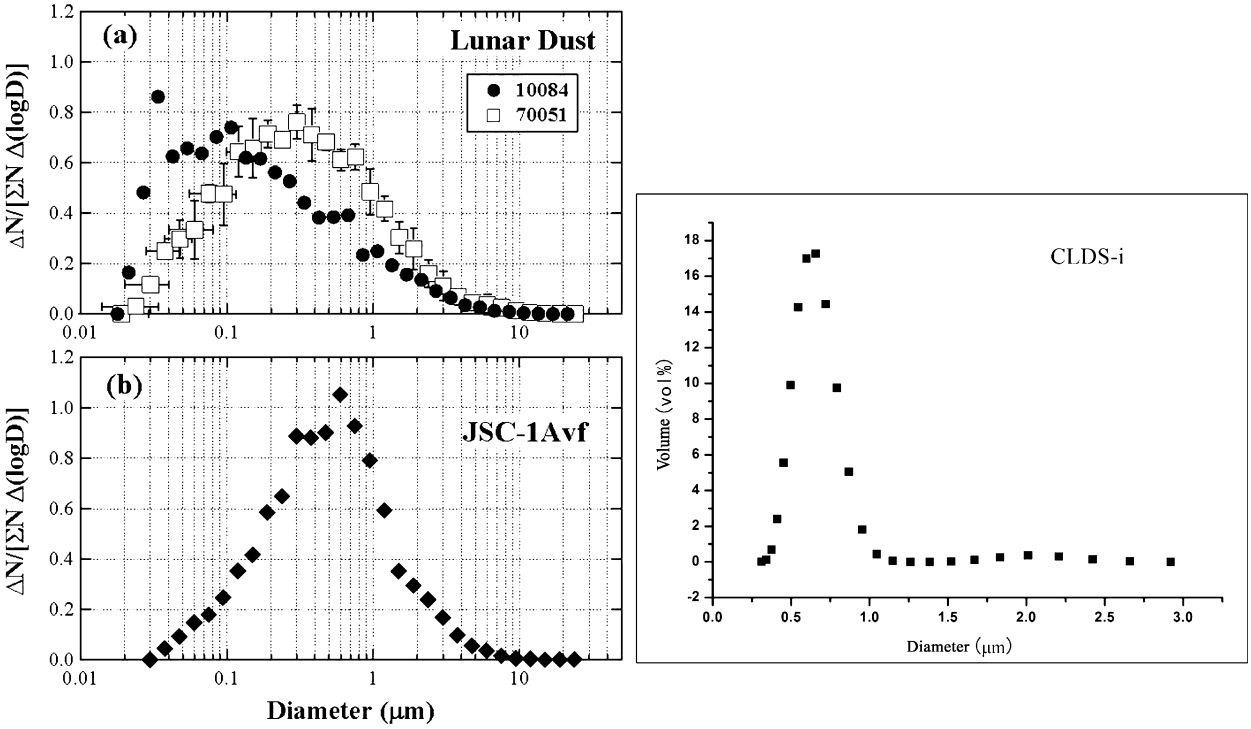

Fig. 2. Particle size distributions of lunar dust, JSC-1Avf, and CLDS-i.

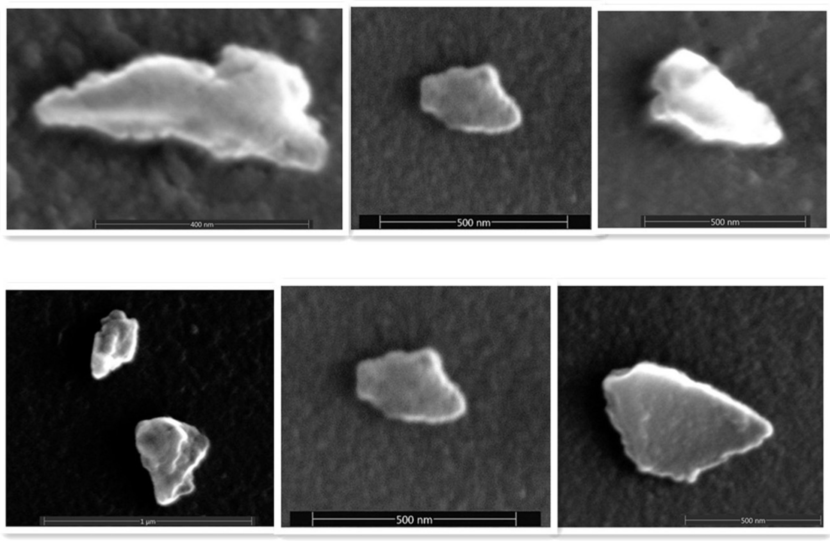

Fig. 3. The morphology of CLDS-i in SEM images.

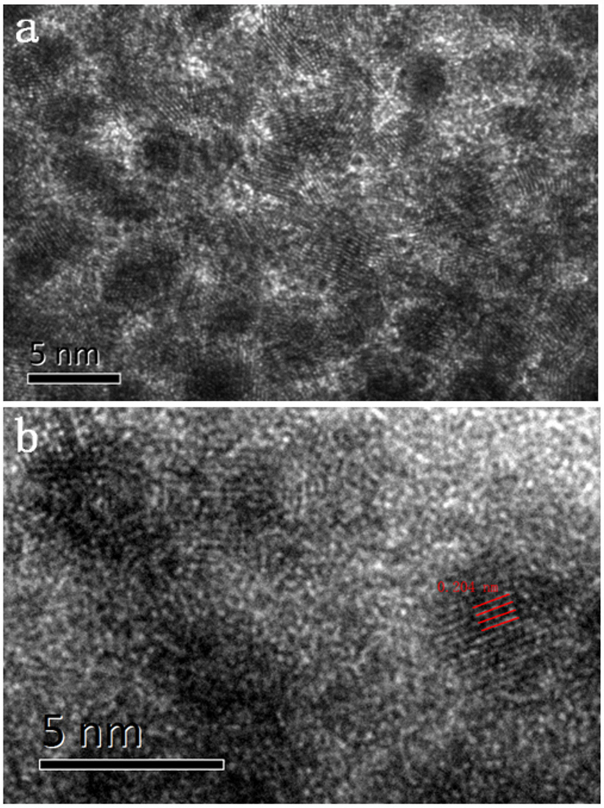

Fig. 4. The HRTEM images of nanophase Fe^0.

the problems of lunar dust, it is necessary to study systematically the basic properties of lunar dust and understand its hazard mechanism to spacecrafts and astronauts. The CLDS-i developed by the Institute of Geochemistry Chinese Academy of Sciences has high similarity to the real lunar dust in chemistry, mineralogy, particle size, morphology, and np-Fe^0, which can be applied to the engineering test in spacecrafts and space suits, as well as toxicological study.

The CLDS-i can be used in dust protection technology researches of spacecrafts and space suits. The harm of lunar dust to spacecrafts and space suits is mainly caused by adhesion and abrasion, which is related to the grain size, morphology, mineralogy, chemistry, and electromagnetic characteristics of lunar dust. The adhesions of lunar dust particles are mainly composed of electrostatic force and magnetic adsorption, which have a close relationship with the grain size, morphology, and electromagnetic characteristics of lunar dust particles. The abrasion of lunar dust to spacecrafts and space suits is related to the hardness and sharp edges of lunar dust particles. The silicate minerals dominated in CLDS-i are non-conductors. In high vacuum with dry and strong radiation environment, these silicate particles would accumulate electrons continuously and be negatively charged, then adsorb to the spacecraft surface by electrostatic force. Due to the smaller size and complicated shape of CLDS-i particles, their surface electric potential is generally large, and might show a very stronger electrostatic absorption. For the presence of np-Fe^0, the CLDS-i particles could easily stick to the electronic components surfaces, even under a very weak external magnetic field. Performing the experiments to understand the effects of grain size, morphology, mineralogy and magnetic properties of CLDS-i on spacecrafts and space suits are essential in developing dust protection technology.

The CLDS-i can also be used in dust toxicological researches of astronauts. The composition, grain size and morphology of lunar dust are important factors that affect the health of astronauts. The CLDS-i with np-Fe^0 could simulate well with the process of np-Fe^0 harm in blood system caused by real lunar dust. The finest lunar dust particle might pass through the bloodstream and np-Fe^0 embedded in the particle surface could reduce the ferric iron in the blood (Liu et al., 2008). Then, it would reduce the oxygen transport capacity of hemoglobin, and may affect the respiratory system in serious cases. For the presence of np-Fe^0, the CLDS-i can substitute the real lunar dust in many toxicological experiments. Moreover, the smaller particle size and the sharp edges of CLDS-i also show a potential application in the other toxicological experiments. Lunar dust particles are very small and can be inhaled easily, which would hurt these organs such as nose, throat, weasand, bronchiole and lung (Liu et al., 2008; Cain, 2010). Most of these particles can be carried deeper into lung, and could cause cough, dyspnea, edema, inflammation and fibrosis (Lam et al., 2013). And for the large specific surface area and sharp edges of the lunar dust particles, they could precipitate in the lungs and damage the pulmonary macrophages. The CLDS-i has very similar properties in these aspects. So, the CLDS-i can be used to study in the effect of mineralogy, grain size and morphology of lunar dust on astronauts. The toxicology experiments with CLDS-i would help to understand the toxicological mechanism of lunar dust and the influence to health.

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