METHODS OF IMPACT EXPERIMENT WITH AL_2O_3 AND Fe MICROPARTICLES

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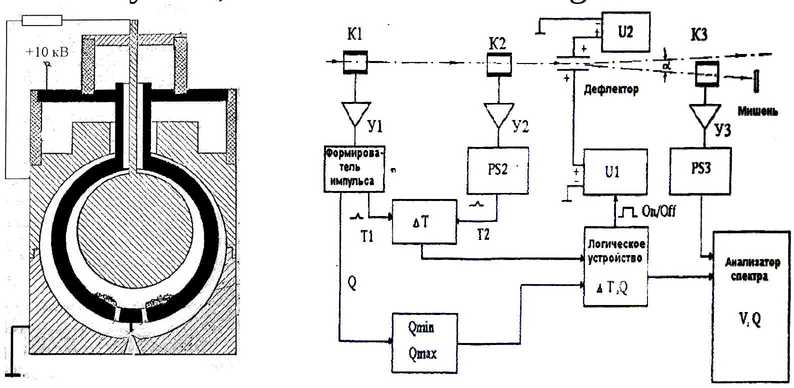
Al_2O_3 microparticles and Fe microparticles are investigated under optical microscope, and their behaviors in the acceleration experiment are also examined. It is concluded that, although Fe is better charged with higher *q* than Al_2O_3, however, Al_2O_3 achieves a higher speed because it is lighter and hollow.

1 Introduction

Al_2O_3 is chosen as the material used in acceleration and impact experiments for the good character – hollow sphere with diameter 1÷2μm and wall thickness h=150÷300nm, which makes it very suitable for high-speed impact experiment, because special substance can be filled into the inner part of the sphere and various phenomenon can be achieved. Besides, the tensile strength of Al_2O_3 is high up to ~10^9Pa. In this paper, the basic form of Al_2O_3 microparticles and their behaviors in the acceleration experiment are examined, comparing with Fe particles.

2 Experimental methods

The forms of the particles were determined under optical microscope named AXIO Imager.A1m, produced by Carl Zeiss Company. The particles were accelerated in microparticle injector of MSU and their velocities and charges were measured with an A/D system, which are shown in Figure 1.



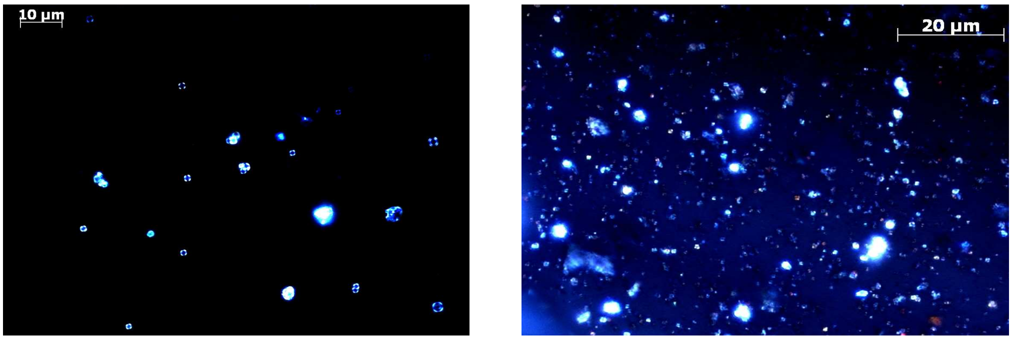
(a) Microparticle injector (b) System of measuring the velocity and charge of particle

Figure 1 Equipment used in the acceleration experiments

3 Results and analysis

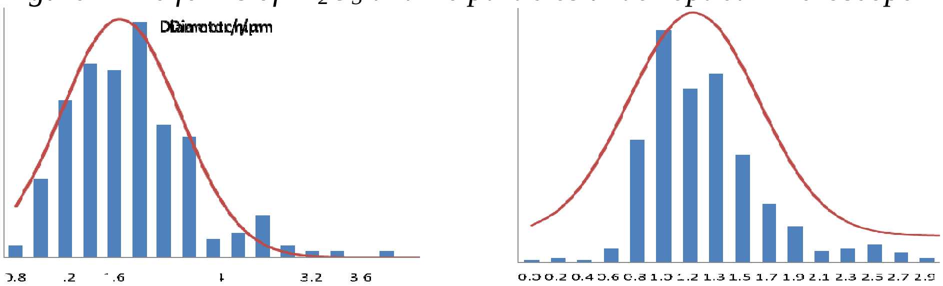
3.1 Particle size

The forms of Al_2O_3 and Fe particles were examined under optical microscope (see Figure 2), and their diameter distributions were investigated using the software supplied with the microscope (see Figure 3). Although Al_2O_3 is much bigger than Fe, but it is much lighter (see Table 1). This is because not only Al_2O_3 has a lower density, but also it is hollow, while Fe particle is solid sphere.



(a) Al_2O_3 particles (b) Fe particles

Figure 2 The forms of Al_2O_3 and Fe particles under optical microscope



(a) Al_2O_3 (b) Fe

Figure 3 Size distribution of Al_2O_3 and Fe particles

Table 1 Size and mass contrast between Al_2O_3 particles and Fe particles

Particles	Al_2O_3		Fe
Sample number	204	204	230
Wall thickness h (nm)	300	150	-
Average diameter (10^{-6}m)	1.69		1.18
Average mass (10^{-14}kg)	0.747	0.444	1.07

3.2 Results of acceleration experiments

3.2.1 Determination of the number of detectors

The parameters of the separate accelerated particles were measured with the help of the two detectors K1 and K2 shown in Figure 1. The particle charge was determined using the amplitude of pulses induced on detectors (Figure 4).

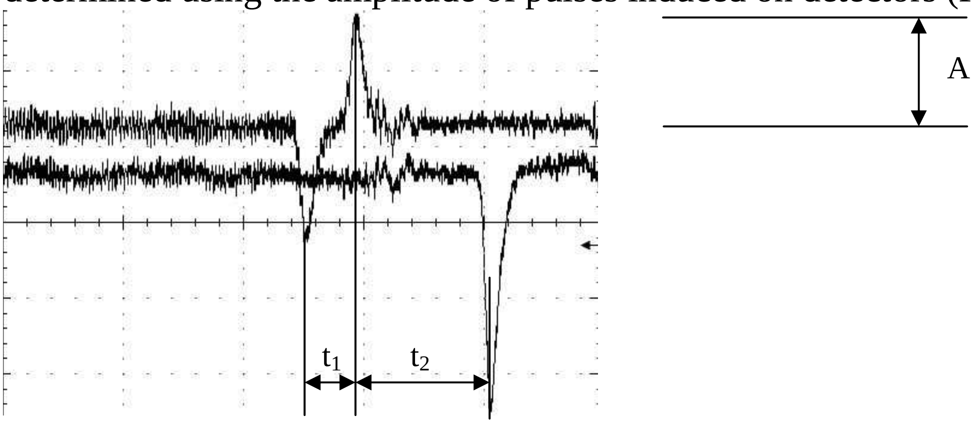


Figure 4 Oscillograms of signals from two ring gauges K1 (upper) and K2 (lower).

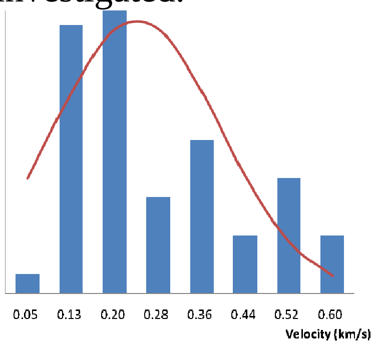
The particle velocity was determined using time of the particle flight either just in K1 (t_1) or between K1 and K2 (t_1+t_2). The results are compared in Table 2, and it is obvious that there are no big difference between using both of the two detectors and using only one detector. It is determined that only one detector is enough for measuring the velocities and charges of particles for the rest work. (It is true if velocities are not too large.)

Table 2 Contrast between two detectors and one detector

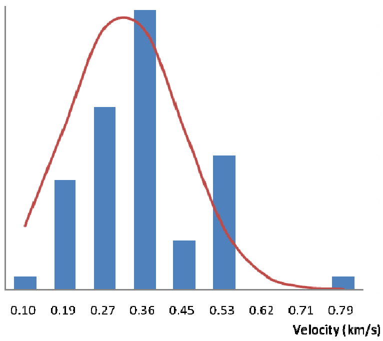
Item	2 detectors	1 detector
Sample number	64	64
Average speed [km/s]	0.3145863	0.3184315
Standard deviation	0.1254	0.1410
Standard deviation of average	0.0157	0.0176
Believe probability	90%	90%
Confidence	0.0256	0.0289
Result	0.3146±0.0256	0.3184±0.0289

3.2.2 Velocity distribution

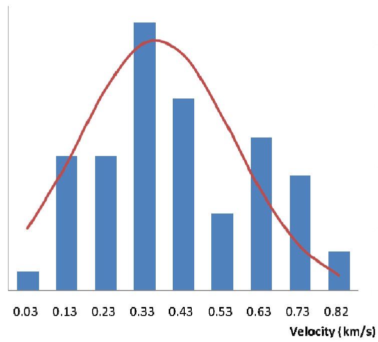
The behaviors of Al_2O_3 and Fe particles in the acceleration experiments were investigated.



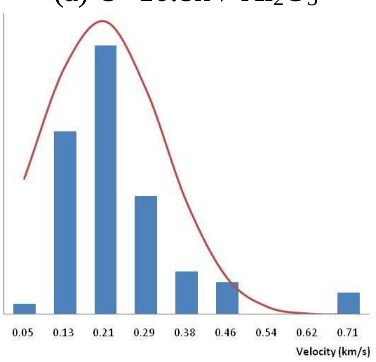
(a) U=10.8kV Al_2O_3



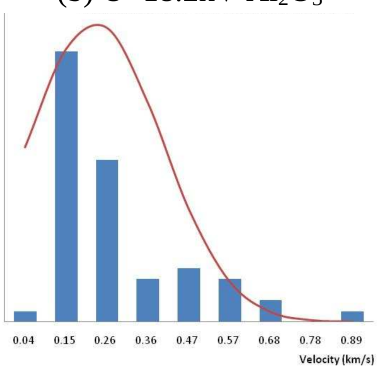
(b) U=18.2kV Al_2O_3



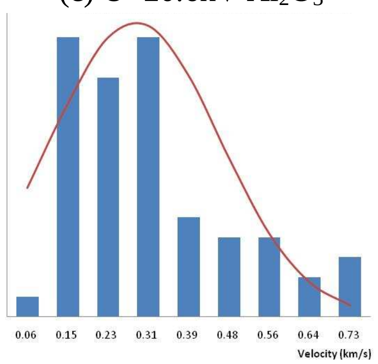
(c) U=20.6kV Al_2O_3



(a) U=13.2kV Fe



(b) U=16.6kV Fe



(c) U=20.6kV Fe

Figure 5 Velocity distributions of Al_2O_3 particles and Fe particles under different voltages

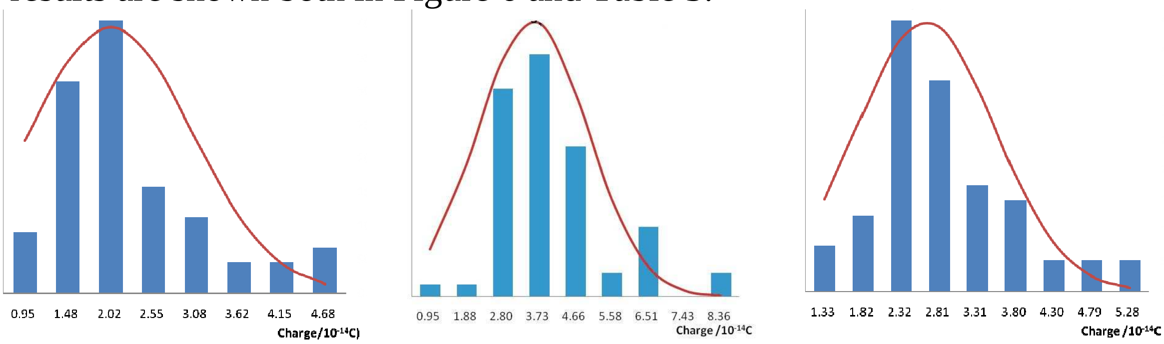
Information for calculating the velocity of particles was achieved by oscillograph. Through statistical calculation, the velocity distributions of Al_2O_3 and Fe under different voltages are shown in Figure 5 and Table 3. It is obvious that, with the acceleration voltage increasing, the average speed of Al_2O_3 is increased, and under the close voltage, Al_2O_3 particle has a higher average speed than Fe particle. Also, we can use higher voltage with Al_2O_3 than Fe without discharges in vaccum chamber.

Table 3 Comparison of average velocity of Al_2O_3 with Fe under different voltages

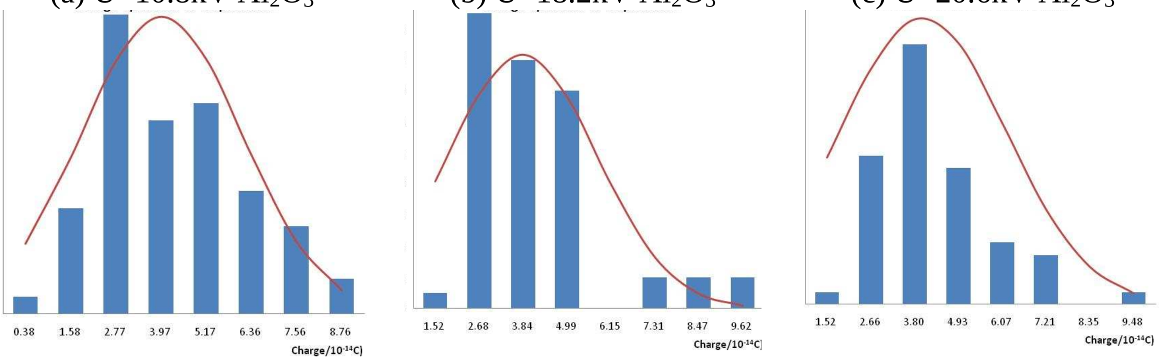
Particles	Al_2O_3			Fe		
Acceleration voltage [kV]	10.8	18.2	20.6	13.2	16.6	20.6
Sample number	56	64	59	63	57	59
Average speed [km/s]	0.245	0.315	0.361	0.202	0.224	0.285

3.2.3 Charge distribution

With the oscillograph data of Al_2O_3 and Fe particles, the charge distribution can be calculated, using formula $q = kA$, where A is the output voltage (see Figure 4) and k is the known (we used calibration of amplifier) coefficient as $1.9*10^{-13}$[C/V]. The results are shown both in Figure 6 and Table 3.



(a) U=10.8kV Al_2O_3 (b) U=18.2kV Al_2O_3 (c) U=20.6kV Al_2O_3



U=13.2kV Fe U=16.6kV Fe U=20.6kV Fe

Figure 6 Charge distributions of Al_2O_3 and Fe particles under different voltages

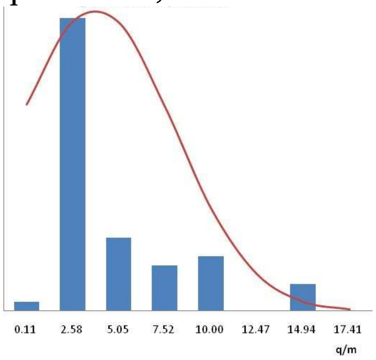
We can see that Fe particles have higher charges than Al_2O_3. Possible reason – that Fe particle is metallic, which is better for charging than non-metallic Al_2O_3.

Table 4 Comparison of charge distribution of Al_2O_3 with Fe under different voltages

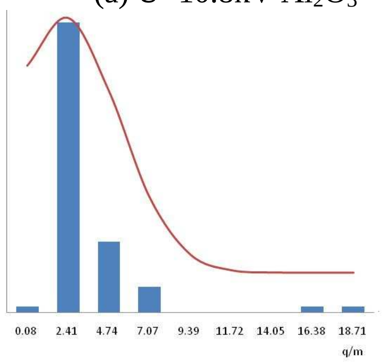
Particles	Al_2O_3			Fe		
Acceleration voltage [kV]	10.8	18.2	20.6	13.2	16.6	20.6
Sample number	56	64	59	63	57	59
Average charge [10^{-14}C]	2.02	3.57	2.64	3.99	3.82	4.01

3.2.4 Specific charge of the particles

The specific charge of the particles q/m can be achieved using this formula: $qU=mv^2/2$, and the results are shown in Figure 7 and Table 5.



(a) U=10.8kV Al_2O_3 (b) U=18.2kV Al_2O_3 (c) U=20.6kV Al_2O_3



(d) U=13.2kV Fe (e) U=16.6kV Fe (f) U=20.6kV Fe

Figure 7 The value of q/m of Al_2O_3 and Fe particles under different voltages

Table 5 Comparison of q/m value of Al_2O_3 with Fe under different voltages

Particles	Al_2O_3			Fe		
Acceleration voltage [kV]	10.8	18.2	20.6	13.2	16.6	20.6
Sample number	56	64	59	63	57	59
q/m [C/kg]	3.79	3.14	4.07	2.14	2.40	2.68

3.5 Analysis

The results achieved in the experiments, together with theoretical calculations, are summarized in Table 6 and Figure 8, in which the obtained relation of the particle parameters with the voltage on the needle is shown.

The theoretical maximum speeds of particles were calculated using formula [2]:

$$v_{\max} = (12\varepsilon_0 E_{\max} U d^{-1}\rho^{-1})^{1/2} = 1.031\cdot 10^{-5}(E_{\max} U d^{-1}\rho^{-1})^{1/2} = 0.326(Ud^{-1}\rho^{-1})^{1/2}[\text{m/s}],$$

Where ε_0 – electric constant; d,ρ – diameter and density of particles, repectively; E_{max} – maximum tension of electric field with a value of 10^9 V/m in our condition, U – potential on the accelaration electrode.

The theoretical maximum charges of particles were calculated using formula[3]:

$$q_{\max} = \pi\varepsilon_0 d^2 E_{\max} = 2.780\cdot10^{-11} E_{\max} d^2 = 0.0278 d^2 [\mathrm{C}],$$

Where d – diameter of particle, E_{max} – maximum tension of electric field, 10^9 V/m.

The specific charge of particle was calculated using formula:

$$q/m = v^2/2U,$$

Where v – velocity of particles, U - potential on the accelaration electrode.

It is visible that, Fe particles have experimental charge values closer to theoretical maximum than Al_2O_3. Although Fe is better charged with higher q than Al_2O_3, however, Al_2O_3 achieves a higher q/m and a higher speed because it is lighter and hollow.

Table 6 Behaviors of Al_2O_3 and Fe particles under different acceleration voltage

	Al_2O_3			Fe		
Acceleration voltage [kV]	10.8	18.2	20.6	13.2	16.6	20.6
Experimental average speed v_{exp} [km/s]	0.245	0.315	0.360	0.202	0.224	0.285
Theoretical maximum speed v_{max} [km/s]	0.449	0.582	0.619	0.408	0.458	0.510
v_{exp}/v_{max}	0.577	0.541	0.582	0.495	0.489	0.559
Experimental average charge [10^{-14}C]	2.02	3.57	2.64	3.99	3.82	4.01
Theoretical maximum charge [10^{-14}C]		8.60			4.52	
Experimental average mass [10^{-14}kg]	2.26	2.18	6.80	7.82	10.7	8.28
Specific charge of the particles q/m [C/kg]	3.79	3.14	4.07	2.14	2.40	2.68

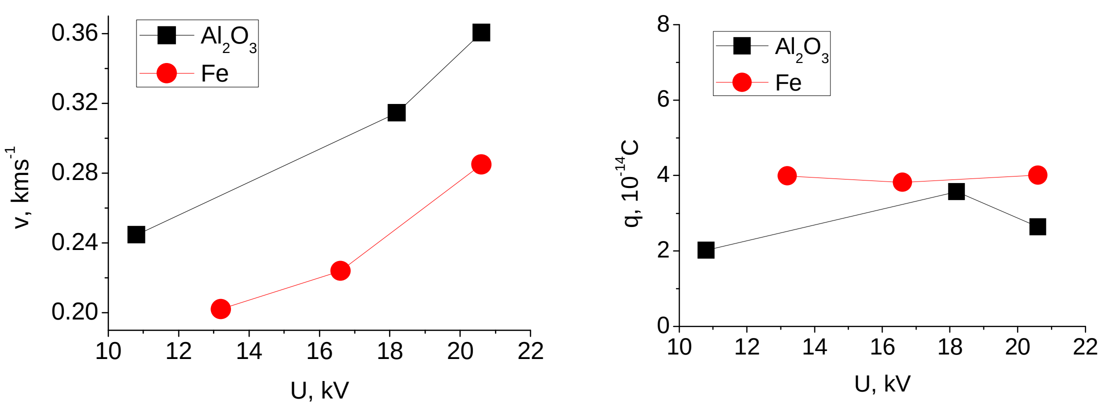


Figure 8 Particle parameters as function of the voltage on the needle

4 Conclusions

As known, metal particles are more easily charged than non-metals. In this work, Fe is better charged with higher q than Al_2O_3, which is non-metal. However, the hollow character of Al_2O_3 makes it much lighter than Fe, although Fe particle is smaller. As a result, Al_2O_3 has a higher specific charge *q/m* than Fe, and accordingly, the velocities achieved on Al_2O_3 particles are higher. But it is still not good enough. The size of Al_2O_3 is too large to achieve higher velocity.

1. Novikov L.S. High-speed impact in cosmos, Moscow, Russia, 2003 (in Russian)
2. Novikov L.S., Voronov K.E., Semkin N.D. et al. Measurement of solid microparticle flux in geosynchronous orbit. In: ESA Symp. Proc. on Environment Modelling for Space-based Applications, ESTEC, Noordwiji, NL, 18-20 September 1996 (SP-392), pp. 343-348
3. Novikov L.S., Bednyakov S.A., Soloviev G.G., Ermolaev I.K., Pilyugin N.N. Laboratory modeling of space particles impact on materials and structures. In: Proc. of the 4th Europ. Conf. on Space Debris, Darmstadt, Germany, 18-20 April 2005 (ESA SP-587), pp. 697-700