Simulating dust monomer collisions: temperature dependence

Yuki Yoshida[1], Eiichiro Kokubo[2], Hidekazu Tanaka[3]

[1]Kobe University, Japan, [2]Astronomical Observatory of Japan, Japan, [3]Tohoku University, Japan,

Dust aggregates grow by collisional sticking, which is the first process of planet formation. In the dust collisions, there are some problems interrupting dust growth. One of the problems is the fragmentation of dust aggregates. When the dust aggregates collide with high impact velocities, they are broken and become fragments. To discuss this problem, we should understand the critical collision velocity of fragmentation, and many numerical simulations of dust aggregate collisions (e.g., Wada et al. 2007, 2008, 2009, 2013; Suyama et al. 2008, 2012).

Dust aggregates are composed of submicron-sized particles, which are called monomers. Numerical simulations have treated dust aggregates as powders and calculated the motion of monomers. Their motions are followed by the contact interactions between monomers using the JKR model, which is one of the elastic contact theories. However, the JKR model doesn't include molecular effects, which lead to viscosity (Krijt et al. 2013; Tanaka et al. 2012). Therefore, the monomer interaction should be investigated including molecular physics.

In this work, we use Molecular Dynamics (MD) simulation to analyze molecular motions and perform the simulations of monomers' head-on collision. We analyze the inter-monomer forces and the coefficient of restitution e and investigate the dependence on temperature.

First, we analyze the inter-monomer forces based on the monomers' motion. We find that there is hysteresis between the loading and unloading phases, which indicates energy dissipation. The force obtained in the MD simulations is smaller than that of the JKR model at the unloading phase although it agrees with that of the JKR model at the loading phase. This behavior is the same for different temperatures. However, the degree of hysteria increases with increasing temperatures. This result suggests that high temperatures result in a large energy dissipation in the collisions. Second, we calculate the coefficient of restitution (COR), which is the ratio of relative velocity between before and after the collisions. For different temperatures, the COR has a peak over the impact velocity. For small impact velocity, monomers are easily sticking due to the surface energy. On the other hand, monomers are deformed, and monomers' kinetic energy dissipates into the thermal and potential energy due to the molecular movements at high impact velocity. Then, the COR has a peak. The COR also decreases with increasing temperature. This agrees with the temperature dependence of forces because small COR indicates strong energy dissipation.

Our results are expected to the scenario of dust growth because the protoplanetary disks have the temperature distribution. We show that that high temperatures result in large energy dissipation in collisions, which suggests that the dust grows more rapidly in the inner region than the outer region. We also expect that the critical fragmentation velocity is large for inner disks. This temperature dependence will affect the theoretical study of dust growth.