Evolution of the chondrules and igneous rim precursors in Shock Waves

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Chondrules are a major ingredient of chondrites and their typical size is 0.1 mm -- 1 mm. They were formed in flush heating events in the solar nebula. Some chondrules have rims, which are enveloping structures composed of small dust grains. There are two types of rims: fine-grained rims and coarse-grained igneous rims. Fine-grained rims resemble the matrix and are thought to be formed by the accretion of fine-grained dust onto chondrules (e.g., Ashworth 1977). Igneous rims have igneous textures suggesting that their precursors experienced melting events similar to chondrule forming events.

Igneous rims are thought to be formed by melting of fine-grained rims (e.g., Krot & Wasson 1995). In this case, igneous rims are expected to be similar in thickness to fine-grained rims. We perform a literature survey of their thicknesses. We also perform model simulations of the dust accretion on chondrules. The thicknesses of fine-grained rims are consistent with the numerical results, which can be expressed as the functions of the chondrule size and dust-chondrule fraction. In contrast, igneous rims are thicker than fine-grained rims. This suggests the other accretion processes for igneous rims.

We focus on one of the leading candidates for chondrule melting events: the shock-wave heating model. In this model, chondrules are heated by their relative velocity to the gas, which is discontinuously decelerated at the shock front. We investigate whether igneous rims are accreted behind the shock front. We develop a 1-D shock wave model based on the Arakawa & Nakamoto (2019) model to reproduce the results of the previous numerical simulations (e.g., Miura & Nakamoto 2005). The relative velocity between the dust grains and the chondrules becomes about the shock velocity, which is ~10 km/s to melt the grains. We find that there are two accretion regimes of the igneous rims: the accretion of supercooled dust and crystallized dust. A molten dust has a high relative velocity to the chondrules and a low viscosity, which prevents accretion. The viscosity of molten dust increases as the temperature decreases, and a molten dust grain can stick to a chondrule in the supercooled state. The crystallized dust grains can be accreted since the relative velocities to the chondrules are low (Matsumoto & Arakawa 2023).

Dust particles with high velocities relative to the chondrules can cause erosion of the chondrules. In particular, molten chondrules can be destroyed when a dust particle collides at > 1 m/s (e.g., Ciesla 2006). We investigate the effect of the collisional erosion of the chondrules behind the shock front. We find that there are three types of results: some of the chondrules with sizes <~ 0.1 mm can survive in the shock wave since they do not experience collisions; chondrules with sizes >~ 0.1 mm survive when they do not melt; chondrules with sizes >~ 0.1 mm are destroyed when they melt. This suggests that the chondrule formation shock waves are dust-free and different from the rim accretion shock waves.

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