Experimental Study on Impact in Groups of Particles and Description of Phenomena by Macroscopic Fluid Dynamic Model

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The collision phenomena in the particle-laden environment, where groups of many particles exist in the vacuum, such as the Saturn's rings, are expected to be described in the way of the fluid dynamics from a macroscopic viewpoint. The collective behavior of such particles is studied as a granular flow. In most cases, however, their speed is relatively low in the absence of the destructive collision. The impact phenomena involving destructive collision into fine grain have not been clarified yet. In the present study, we experimentally simulated such phenomena by using the ballistic range, which launched a projectile or a group of particles into a sheet of free falling particles. Some of the characteristic features of their dynamics cannot be simulated in the framework of the conventional compressible fluid dynamics. For example, a granular medium does not have the random thermal motion of particles, resulting in the absence of the expansion wave propagating in the vacuum region. Consequently, the Compressible and Non-Expanding (CNE) fluid model (Suzuki, K., AIAA Paper 2016-4107, 2016) seems promising because of its unique property of irreversible compression.

The experiments were conducted by using the ballistic range, which launched a projectile tangentially into a sheet of glass particles (0.2 mm dia.) falling through a slit with 2 mm width and 600 mm length in the test chamber at pressure about 35 Pa (Masaki, C. et al., ISTS 2017-e-48-s, 2017 and FLUCOME 2017). The behavior of the particles and the projectile was recorded by the high-speed camera with 20,000 fps and 0.001 ms exposure. The typical projectile was a hollow sphere with 25.75 mm diameter and 4.3 g mass made from the polycarbonate. It was launched at the velocity up to 430 m/s. A bow-shaped condensed zone was formed in front of the projectile, and no disturbance was observed in front of that zone. Such observation suggested that the particles behaved like a compressible fluid over a supersonic body. The shock-layer-like structure was made from fine grain produced by the destructive collision of particles at the surface of the projectile. In the opposite side, the void was formed in the trail of the projectile.

A jet of particles was generated by launching particles in the hole made on the front surface of the cylindrical projectile. The cylinder was forced to be stopped at the sabot separation plate. A series of snapshots at the jet velocity 176 m/s show that the high-density zone was formed in front of the head of the particle jet. The high-density zone was smeared as it was penetrating on the particle sheet because of the presence of the macroscopic diffusion effect. The void was formed and remained at the impact point like a crater.

In the irreversible compression of the CNE fluid model, the density remains higher after unloading than its initial one before compression, by assuming that the speed of sound for the compression is lower than that for unloading. The numerical analysis of the CNEF fluid flow is made by the similar way to the conventional compressible CFD analysis in the framework of the finite volume method and the Godunov scheme (Suzuki, K., ISTS 2017-k-47, 2017). The fundamental solutions of the Riemann problem are composed of the irreversible compression shock wave, the elastic (reversible) wave, the contact discontinuity, and the contact surface to the vacuum at zero pressure. The numerical results for the case with the jet velocity 176 m/s and the speed of sound for compression 75 m/s qualitatively agree with the experimental images. Further improvement is expected by introducing the variable speed of sound, that is, the speed of sound increasing with the density and the effect of viscosity of the Navier-Stokes type.

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