EPSC Abstracts
Vol. 6, EPSC-DPS2011-120, 2011
EPSC-DPS Joint Meeting 2011

Growth and Erosion - Conquering the Meter-Size Barrier?

J. Teiser, I. Engelhardt, M. Küpper, G. Wurm,
Faculty of Physics, University Duisburg-Essen, Duisburg, Germany (jens.teiser@uni-due.de / Fax: +49-203-3791965)

Abstract

Decimeter-size bodies play an important role for planetesimal formation, as they have to grow fast to conquer the meter-size barrier. Within this work we present experiments on the mechanical properties of evolving dust agglomerates and the collision conditions at large impact velocities, which is important for coagulation models as well as for the development of gravitation driven growth models.

1. Introduction

The process of planet formation starts with the coagulation of micron sized dust grains to macroscopic dust agglomerates within protoplanetary disks. The very first growth step, from µm to mm-sizes appears to be well understood, experimentally as well as theoretically [1,2]. The further growth still offers many unsolved problems, as the collision velocities increase with the particle sizes and compaction, bouncing and erosion start to occur [3]. Large dust agglomerates, especially m-sized objects, have only very short lifetimes in protoplanetary disks, as they drift rapidly towards the central star and are finally accreted [4]. It is therefore crucial to investigate the properties of decimeter-sized objects, as they are supposed to be the immediate precursors of the critical meter-sized bodies. Current models describing gravitation driven growth also strongly depend on the properties of decimeter bodies, as they are based on the assumption that all material is captured within aggregates of decimeter size [5]. Within this work, experimental studies on the properties and on the evolution of decimeter-sized dust agglomerates will be presented. Additional experiments on the further evolution will be presented, in which collisions at impact velocities of 20 m/s at varying impact angles will be presented.

2. Experimental aspects

To analyze the properties of evolving dust agglomerates, an experimental setup has been developed by [6] to investigate the self-consistent growth of macroscopic dust aggregates. A dense beam of small (~ 100 µm) dust agglomerates is generated. Targets of different sizes (3 mm – 3.5 cm) are exposed to this particle stream at varying collision velocities (1.5 m/s – 7 m/s). Targets grow by direct sticking as well as by re-accretion due to gravity. As macroscopic dust agglomerates in protoplanetary disks are subject to a constant head wind, gas drag accelerates impact ejecta back to the surface. This is simulated in the experiments by gravity, as the gas drag in protoplanetary disks is of the same order. To study the further evolution collision experiments at 20 m/s impact velocity are carried out with mm-sized projectiles and dm-sized targets at varying impact angles between 0° (central collision) and 45°. The setup for these experiments has first been developed by [7] and mainly consists of a crossbow as launcher and a highspeed camera with stroboscope illumination. All experiments are carried out with compressed dust agglomerates with a volume filling of about 32%. The samples consist of quartz dust with a broad grain size distribution (80% of the mass between 1 µm and 5 µm). As the mechanical properties of dust agglomerates do not depend on the mineralogical composition, but are dominated by the grain size distribution, this material is considered to be comparable to materials in protoplanetary disks.

3. Results

At collision velocities between 1.5 m/s and 7 m/s agglomerates grow by re-accretion and direct sticking. With increasing collision velocities the volume filling of the growing aggregates also increases from 0.2 to 0.32. Once a collision velocity of 5 m/s is reached, the volume filling does not increase further, but reaches a saturation level of 0.32, which is consistent with studies by [6] and close to the maximum compression feasible by local pressure [7], as seen in Fig. 9 [8]. Depending on the target size the ratio between re-accretion and direct sticking changes, as the probability for ejecta landing on the target is smaller for smaller targets. However, all targets have the same shape, independent of target size and impact velocities. The volume filling does not depend on the target size, so the analyzed growth mechanism is self-consistent and can be treated as a good analog for macroscopic bodies collecting small particles in protoplanetary disks.

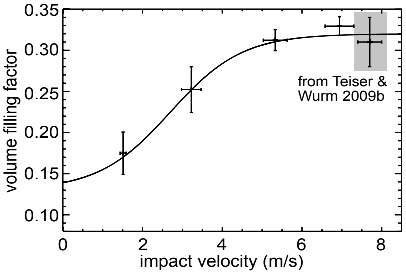

Figure 1: Volume filling of evolving dust aggregates and its dependency on the impact speed [8].

Experiments at large collision velocities show that growth is possible at impact speeds of up to 56 m/s, if the projectiles are smaller than a critical size [7]. This critical size decreases with increasing impact velocity from 4 mm for 20 m/s to about 0.5 mm for 56 m/s. New experiments show that growth is not only possible for central collisions, but still possible at impact angles of 45°. However, the critical size for growth also decreases with increasing impact angle, as seen in Fig. 2 [9].

4. Conclusions

Experiments on self-consistent growth show that macroscopic dust agglomerates are compact with a volume filling of 0.32, which is close to the maximum feasible by local compression [6,8]. The collision history is erased by following impacts. Experiments at large impact velocities show that growth is possible even at the largest impact speeds expected for protoplanetary disks. Large projectiles lead to slight target erosion, but are ground to smaller sizes and the material then can be captured by another large aggregate. With such a fragmentation-growth cascade net growth is still possible and the meter-size barrier might be conquered, eventually.

Acknowledgements

This work is part of the DFG research group FOR 759, The Formation of Planets.

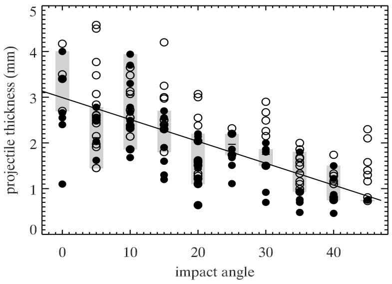

Figure 2: Critical sizes for growth at 20 m/s and its dependency on the impact angle [9]

References

[1] Blum, J. and Wurm, G. 2008. The Growth Mechanisms of Macroscopic Bodies in Protoplanetary Disks. Ann. Rev. of Astronomy & Astrophysics, 46, pp.21-56

[2] Dominik, C. and Tielens, A.G.G.M., 1997. The Physics of Dust Coagulation and the Structure of Dust Aggregates in Space. ApJ, 480, 647-673.

[3] Güttler et al. 2010. The outcome of protoplanetary dust growth: pebbles, boulders, or planetesimals?. I. Mapping the zoo of laboratory collision experiments. A&A, 513, id. A56.

[4] Weidenschilling, S. J. and Cuzzi, J. 1993. Formation of planetesimals in the solar nebula. In: Protostars and planets III (A93-42937 17-90), p. 1031-1060.

[5] Johansen, A. et al. 2007. Rapid planetesimal formation in turbulent circumstellar disks. Nature, 448, 1022-1025.

[6] Teiser, J. and Wurm, G. 2009b. Decimetre dust aggregates in protoplanetary discs. A&A, 505, 351-359.

[7] Teiser, J. and Wurm, G. 2009a. High-velocity dust collisions: forming planetesimals in a fragmentation cascade with final accretion. Mon. Not. RAS, 393, 1584-1594.

[8] Teiser et al. 2011a. Porosities of Protoplanetary Dust Agglomerates from Collision Experiments, in review.

[9] Teiser et al. 2011b. Impact Angle Influence in High Velocity Dust Collisions during Planetesimal Formation. Icarus, in review.