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Experimental research on the angle of repose for granulated materials

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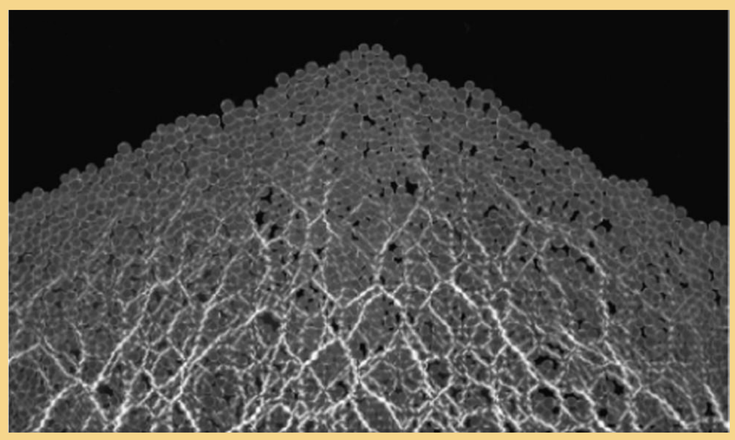
Introduction

Granular materials consist of **many macroscopical particles**, like those fascinating spices, which can be poured in a **cone-like shape**. If the angle of the cone to the horizontal is bigger then the **angle of repose** (α) particles slide down in avalanche form. To determine the critical values of α for different materials and circumstances I must take into consideration the so-called **force chains** [1].

This chains are determined by the forces below:

$$\sum \vec{F_i} = m_i \vec{g} + \sum_{j=1}^{n} \vec{F}_{ij,friction} + \sum \vec{F}_{ij,normal} + \sum \vec{F}_{i\,cohesion} = 0$$



Force chains

Research methods

There are **numerous setups** for measuring angle of repose and each produces slightly different results. Results are also sensitive to the exact methodology of the experiments. In the experiments I have investigated **relevant parameters** like the shape of the pile, the height of the pouring, the size and shape of the particles, the quality of the materials and the effect of mixing different materials. The particles were examined with VHX 2000 **microscope**. The angles were determined **by video analysis.**

The two best working setups, which give pretty much the same results for each material. The height of the pouring and the quality of the ground were unvariable.

Effect of the size of the particles

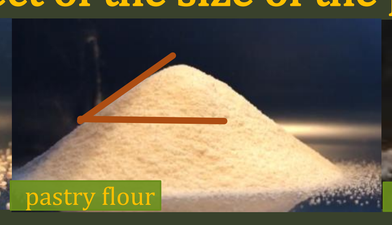
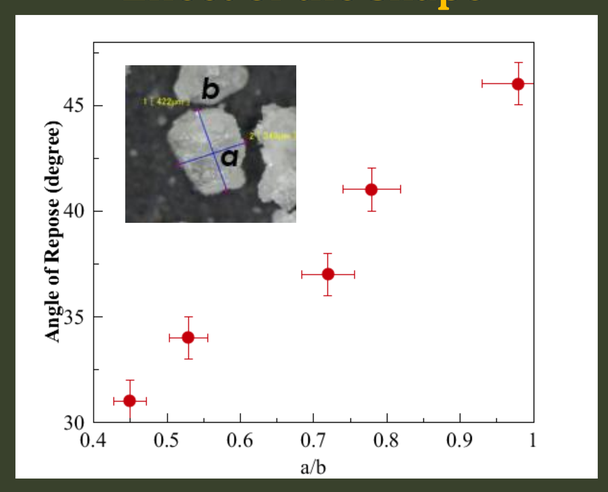


Table 1

Name of the material	Width of the particle (μm)	Length of the particle (μm)	Angle of Repose (degree)
Semolina	741	1293	33-36
Pastry flour	262	471	38-41
White flour	2,39	2,82	42-46

From the Table 1 and the pictures below is clearly be seen, if the other factors besides the size of the particles are unvariable, the smaller the size, the larger the angle become.

Effect of the shape



It is clearly visible, the more symmetric the particles are, the larger the angle become.

Conslusion:

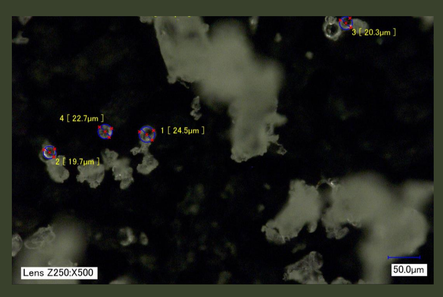
How can be reached the biggest angle of repose?

The **biggest angle of repose** depends on the **size and shape of the particles** and **the humidity of the materials**. Because it also depends on the setup, I made measurements on **different surfaces** and the materials were **poured from a variable height**.

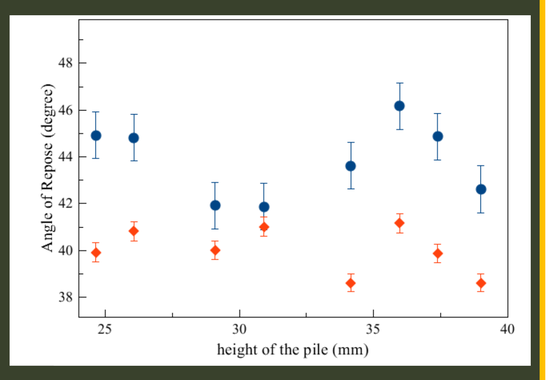
- Roughness of the ground ⇨ Possibly not too smooth
- Height of pouring ⇨ Possible small
- Shape ⇨ More symmetric
- Roughness ⇨ More rough
- Humidity ⇨ Possible big
- Size ⇨ Possible small

Effect of the humidity of the material

By plain white flour is the humidity also noticeable. Liquid bridges are formed at the contact points of grains. Cohesive forces act through the liquid bridges, which have an effect on the normal forces as well and provide a larger angle [2].



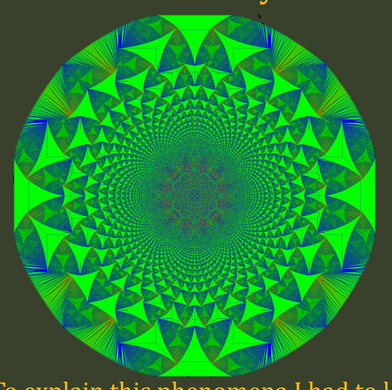
The humidity of the flour was reduced by putting in the oven for 30 minutes at the temperature of 60°C. Between the two conditions of the flour I noticed a difference in the angles about five degrees (blue is the first condition, and red is the second). It means, that the friction force grows about 5% due to the extra cohesion forces.



Effect of mixing

When I worked with mixed materials, stratification was sometimes noticeable, which means that the particles with different properties accumulate in different compartments.

It has some passages, like the density of the materials or their particlesize have to be very different.



To explain this phenomena I had to look into the Sandpile model from Bak-Tang-Wiesenfeld. The colors represent how many grains are at each vertex.

[1]H.J. Hermann: On the shape of the sandpile, available online at http://www.comphys.ethz.ch/hans/p/224.pdf
[2] Namiko Mitarai and Franco Nori: Wet granular materials available online at https://arxiv.org/pdf/cond-mat/0601660.pdf