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Experimental study on rheology of low friction natural phenomena

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Extended Abstract

INTRODUCTION

Some dangerous natural phenomena, like large rock avalanches and faults slipping during earthquakes, show a peculiar behaviour characterized by a very low friction. Many attempts have been advanced by scholars in the last decades in order to explain that behaviour, but none of them have been generally accepted by the international community. This study takes into consideration the effects of dynamic fragmentation on the mechanics of rock avalanches and faults motion in order to explain the slip weakening shown by these phenomena at the sliding surface. Experiments have been conducted by means of a high pressure rheometer purposely built capable to apply a direct stress up to 4 MPa on a sample of rock granules. First results are promising toward an advance in understanding the motion mechanics of rock avalanches and the prediction of their runout possible reach.

The dynamic effects of grain fragmentation on phenomena characterized by a granular shear have not been object of much studies, in spite of the importance of these phenomena, cited above, have on human life (e.g. G. Di Toro et al., 2004). The aim of this study is to raise some attention on the fact that fragmentation itself can reduce the frictional resistance of a comminuting granular shear flow. On the other hand fragmentation is always present when geological phenomena show a low friction behaviour and this induces the idea that granular comminution has some role as a source of low friction, with or without some other shear weakening mechanisms.

The basic idea is that in a high pressure granular shear flow there is a conversion of elastic strain energy to pressure energy exerted on the surroundings when a grain fragments; there is a consequent reduction in effective intergranular stress among the nearby non-fragmenting grains. The fragmenting grain loses its shear strength, and the shear resistance of its neighbours reduces in proportion to the reduction in their effective stress. The performed laboratory tests try to demonstrate that fragmentation of rock does not involve significant loss of free energy to surface energy, and that most of the fracture surface energy instead is returned to the flow as kinetic energy (McSaveney & Davies 2008, Deganutti et. al. 2010).

FRAGMENTATION RHEOLOGY - METHOD

Laboratory apparatus

In order to obtain some laboratory evidence of the role of granular fragmentation on friction, a specially designed rheometer has been built (Davies et al., 2005). The original idea at the base of the project was to build a machine able to shear a fragmenting granular flow, rather than to propose another apparatus doing rock on rock sliding (e.g. Marone, 2004; Reches & Lockner 2010).

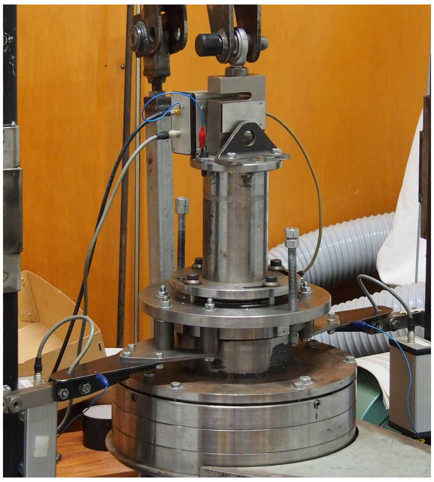

Figure 1. Modified fragmentation rheometer apparatus

In its first design the fragmentation rheometer proved to be able to fragment only not very hard rock grains, but was anyway useful in showing some friction reduction when coal granules were tested with a pressure up to 0.3 MPa. In the last two years the rheometer has been deeply modified reducing the dimensions of the annular test cell (sample space) and improving the electronics of the whole apparatus, both in data collection from sensors and in motor control.

The reduced sample space (radial width from 5 to 0.5 cm) permits to reach a maximum direct stress of about 4 MPa on sample.

The set of installed sensors comprises:
- one vertical load cell which measures the direct load and hence the direct stress on sample during tests
- two torque load cells measure the reaction torque on the stationary upper loading plate from which the shear stress is inferred
- one linear vertical displacement transducer (LVDT) keeps record of the vertical displacement of the loading plate
- one rotary encoder measures the rotation velocity of the sample holder.

The calibration of sensors and the necessary high precision of mechanical settings required an extensive work of a team of scientists and technicians. Many preliminary tests have been performed in order to reach the necessary working precision of the whole apparatus (fig. 1). In particular tests done putting a nylon ring in the sample space gave a measure of the apparatus rotation friction.

The higher pressure on the sample cell makes the rheometer able to comminute rocks harder than coal, like limestone and argillite.

Laboratory Tests

A series of tests have been performed with 0.4 mm glass beads as sample material and, in order to avoid the presence of grains in machine clearances, some drops of water were put on the surface of the sample and this "trick" proved to be rather effective in preventing the breaking effect of glass beads stuck between the rotating and the stationary parts of apparatus (clearances).

The test procedure starts putting the sample in the sample space (channel) then making its surface plain and smooth and put just a few drop of water on it. Then the sample holder is bolted on the rheometer body, the upper loading plate is lowered on sample by means of a small crane and some weights are applied on the loading arm in order to reach the wanted loading conditions.

Then the data collection system and motor control hard/software are started, being a Scientific Linux PC the control console.

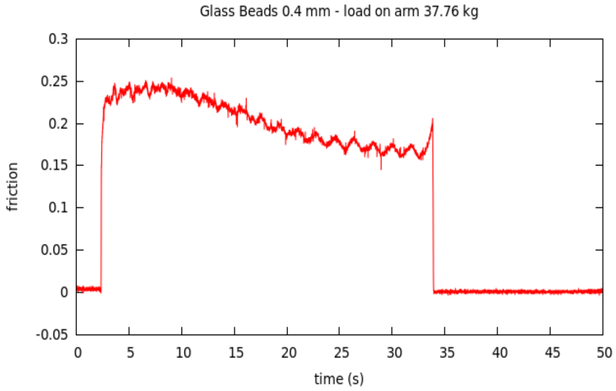

Figure 2. Friction in a mid load test

RESULTS

In fig. 2 an example of the friction trend is shown, the graph was recorded during a test on 0.4 mm glass beads with a 37 kg load on arm (corresponding to a pressure on sample of 2.08 MPa): a friction reduction is evident, its coefficient goes from 0.24 to a value as low as 0.17, corresponding respectively to friction angles of 13.5° and 9.6°. The initial low friction is due to the rolling capability of the glass beads whose following comminution causes a further reduction in friction.

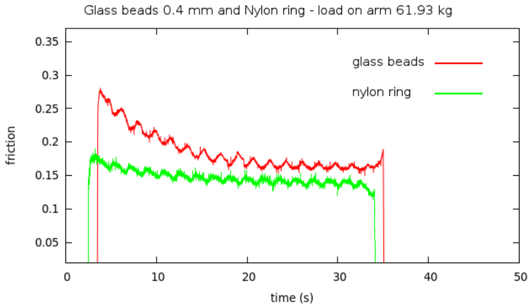

Figure 3. Comparison of friction results

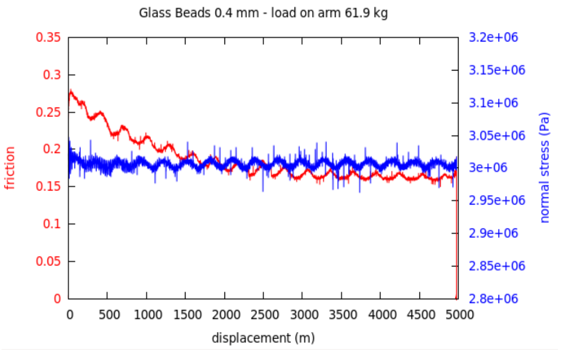

Figure 4. Friction and normal stress vs. displacement

In fig. 3 it is possible to see the results of two tests with an arm load of 62 kg (corresponding to a pressure on sample of 3.01 MPa): a nylon ring test (calibration test done with a nylon ring in the sample channel) and a glass beads one. In this plot it is possible to see the friction has an initial phase of reduction and reaches a steady state after about 20 seconds (corresponding to a sample displacement of about 2000 m); the nylon test shows obviously a lower friction with a slight tendency to some reduction probably due to frictional heating.

It is worth noting the steady state of friction requires a longer shearing to be achieved with a lower load, as it is possible to see from the comparison between the friction plots of figures 2 and 3; this is clearly an effect produced by the fragmentation process which works faster with higher load. The small friction peak at the end of the recordings is due to an inertial reaction at the sudden stop of the motor.

In figure 4 friction is plotted together with normal stress which is constant save some noise and oscillations (the same of friction) probably induced on the loading arm (and from that to sample) by the unavoidable vibrations produced by the electric motor.

During tests the fragmentation process produces a reduction in volume of sample material; this is measured by the LVDT as a downward displacement of the upper plate, shown in fig. 5; the loading arm oscillation are obviously present as vertical up-and-downs of the upper plate of the order of 0.15 mm. In fig. 5 it is also possible to observe that the downward movement of rheometer upper plate follows initially a parabolic trend becoming linear in a second stage (at a displacement of aboud 2500 m); this behaviour can be explained as the effects of initial fragmentation and then of a reduction of volume due to some fine glass dust extrusion from the sample channel (fig. 6).

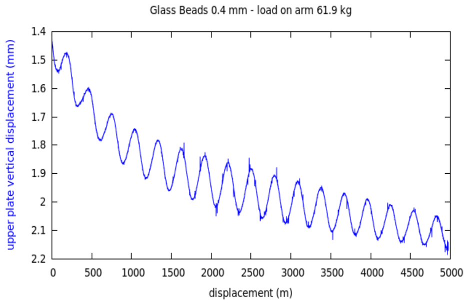

Figure 5: Vertical displacement

Figure 6. Sample after a mid pressure test

Test effects on material

After tests the glass beads are thoroughly fragmented to dust in the upper part of the sample (fig. 6) while a layer of intact beads remain on bottom. Probably after the first phase of comminution the produced fine dust (comparable in size to fault gouge) acts as a layer of powder lubricant (Reches & Lockner 2010, Wornyoh et al. 2007) preventing a deeper fragmentation action. As said, some glass dust was extruded during the test from the sample channel.

Some scanning electron microscope (SEM) images have been taken from samples after tests: in fig. 7 a sample after a low pressure test, taken from the separation limit between the comminuted layer and the underlying shear-unaffected beads: it is possible to observe the thoroughly fragmented glass powder together with an intact bead embedded in it. In a more detailed image the shape of glass fragments is evident (fig. 8).

CONCLUSIONS

Fragmentation is a process that is ubiquitous in geological low friction phenomena like rock avalanche runout and fault slipping during earthquakes. After a first series of tests with glass beads, the modified fragmentation rheometer has proved to be a promising tool for the study of the dynamics of a flow of comminuting particles. An evident reduction in friction linked to the initial phase of fragmentation has positively been recorded. Of course some mechanical improvement are necessary in order to avoid the observed oscillations in recordings.

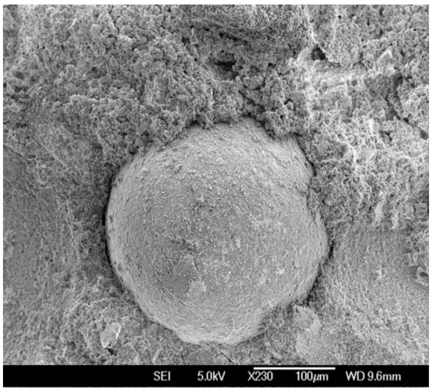

Figure 7. SEM image of a sample after a low pressure test

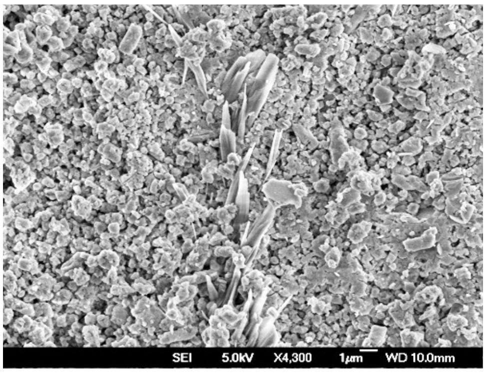

Figure 8. SEM image: details of fragmented glass powder

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