

FIG. 1. (Color) Experimental setup and image acquisition. Left: top view; right: side view.

### Force chains in a two-dimensional granular pure shear experiment

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(Received 17 September 2008;

published online 30 December 2008)

[DOI: [10.1063/1.2997139](https://doi.org/10.1063/1.2997139)]

Understanding the behavior of granular materials under slow shear has wide applications in soil mechanics and many industrial and engineering processes. The experiment shown in this video visualizes the evolution of force chains using assemblies of photoelastic disks.

Figure 1 shows a sketch of the biaxial device. On the left is a top view of a rectangular frame whose left and bottom walls are mobile. The motion of the two walls can be precisely controlled by computer-regulated translation stages. The frame, mounted on top of a horizontal Plexiglas sheet, is filled with 1578 bidisperse photoelastic disks. The frame is set to a square ( $x_0=y_0=30.5$  cm) at the beginning, with the initial state chosen to be unjammed so that no contact forces are carried between disks. The initial configuration of the disks is isotropic and homogeneous. The frame is gradually deformed by applying pure shear, which means compression in one direction with equal dilation in the other while the frame area remains constant. This process is carried out slowly and in small increments. There is a total of 29 deformation steps in both the forward and the reverse shears. The packing fraction is 0.763 and the maximum strain  $(x-x_0)/x_0$  is 0.097. In the forward shear, compression is along the  $y$  axis and, after step 29, the shear is reversed with compression along the  $x$  axis. At the end of the reverse shear the frame returns to a square.

The right-hand side of Fig. 1 shows that the whole device is sandwiched between two crossed polarizers. If a particle carries contact forces, the resulting photoelastic image within the particle consists of a series of light and dark bands which encode information on these forces.<sup>1</sup> Figure 2 shows a snap-

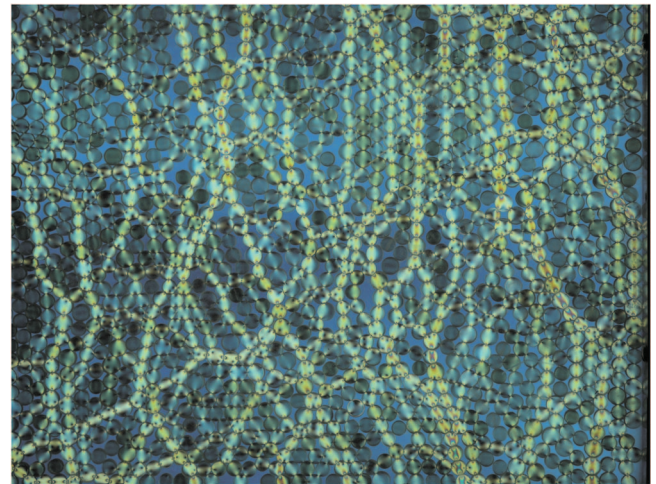


FIG. 2. (Color) Photoelastic image showing the force chains at strain 0.097 in the forward shear (enhanced online).

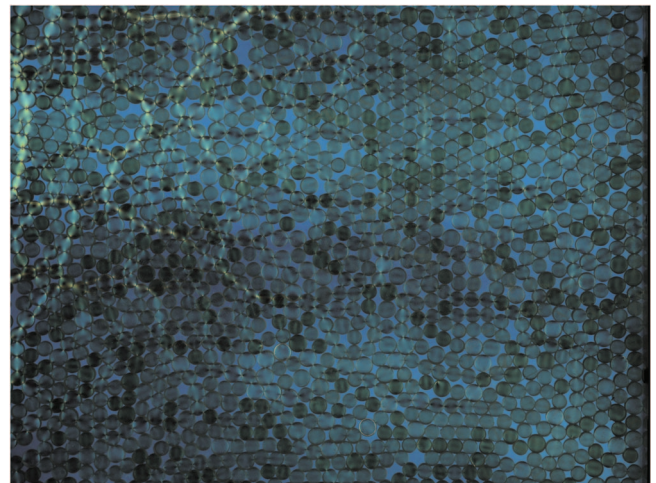


FIG. 3. (Color) Force chains are eliminated at strain 0.057 in the reverse shear.

shot of force chains at strain 0.097 in the forward shear. Disks carrying more than average contact forces are brighter. A lighter color signifies contact and the darker, original color indicates no contact. The system is jammed at this step since the average contact number is larger than 3, the presumptive isostatic number for frictional particles. After the shear reversal, the force chains are gradually eliminated and the system unjams. Figure 3 shows that at a strain of 0.057 in reverse shear most of the force chains disappear. Some weak force chains remain in the left corner due to the weak friction between the disks and Plexiglas sheet.

This work was supported by NSF Grant No. DMR0555431 and ARO Grant No. W911NF-07-1-0131-00.

<sup>1</sup>T. S. Majmudar and R. P. Behringer, *Nature (London)* **435**, 1079 (2005).