Lightning in The Frame

The Force Chains in The Compressed Granular System

Jia-Jun Xu(徐嘉駿), Hong-Xiang Chang(張紘翔), Hsin-Wen Huang(黃信雯), Ke-Si Chiang(江科熹)Cheng-Han Wu (吳承翰), Chia-Ming Kuo(郭家銘)
Department of Physics, National Central University, Chung-li, Taiwan

To study the force transition, we built a two dimensional compressing system. We constrain the particles in a square area and we use the stepping motor to push our two sides to compress the granules. To measure the stress among the particles, we obtain the intensity of the fringe pattern. What we want to measure is the average stress of the particles. We use the gradient of the light intensity to quantify the stress and integrate the full picture to calculate the average stress. Finally, we can observe the propagation direction of the force in the system.

Introduction

As the light passes through the birefringence material[1] with compression, different fringe patterns can be observed, due to different diffraction indexes. This phenomenon is called photoelasticity[2]. By using this optical feature, we want to analyze the force transmitting in the compressed system.

Photoelastic Effect

If the light with a certain polarized direction goes through a birefringence material, the light will refract two different lights. These two lights interfere with each other, and the fringe pattern can be observed. As the material is under an external force, its structure is changed. In this case, the refraction index of the material becomes different. The relation between the stress and the light phase retardation causing the fringe pattern follows the stress-optic law[3]

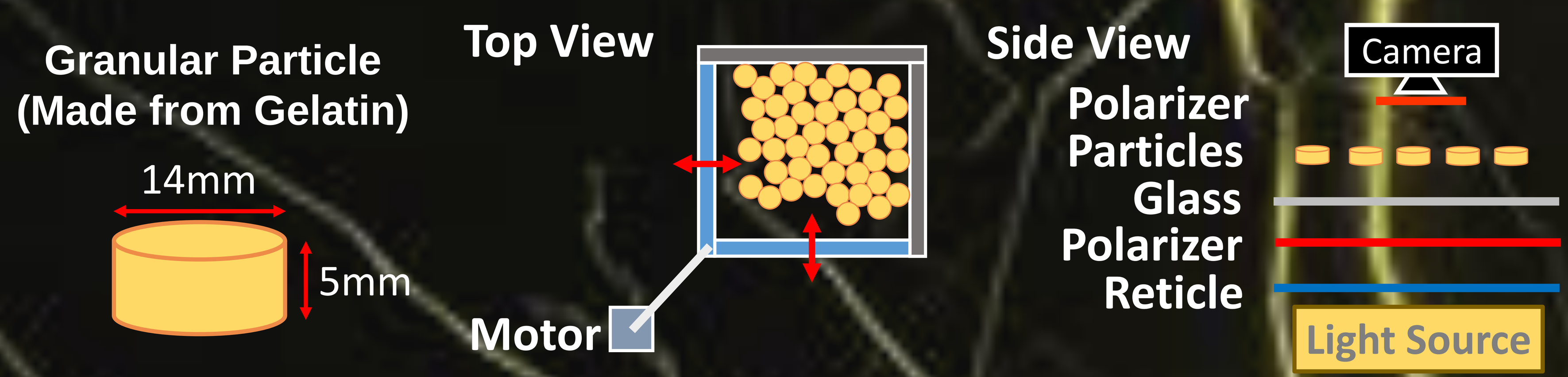
$$\Delta = \frac{hc(\sigma_1 - \sigma_2)}{\lambda}.$$

Δ is the phase retardation, h is the thickness of the particle, c is the stress-optic coefficient, σ is the stress, and λ is the wavelength. This phenomenon of the fringe pattern changing which is caused by different stresses called photoelastic effect. The light intensity of the fringe pattern at any point is

$$I(x,y) = I_0 sin^2(\pi\Delta),$$

I is the light intensity and I_0 is the incident light intensity. Therefore, the local stress can be known from the light intensity.

Experimental Setup



The granular particles(circular, triangular and rectangular) are made from Gelatin, a good photoelasticity material. The system is compressed by two moving sides driven by a stepping motor. As the system is compressed, the photoelastic effect of the granular changes. Then, the change is recorded by the camera whose lens is attached by a polarizer.

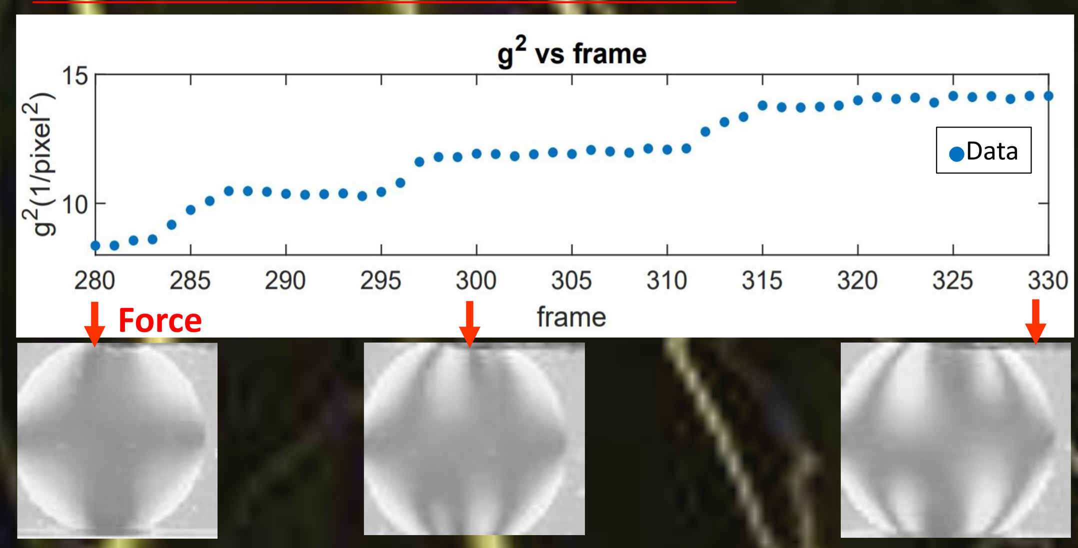
Analyzation

After tapping the video, it is turned into the grayscale. The gray value of each pixel can be obtained, and the gray value presents the light intensity. The square of local gradient light intensity (g^2) [4] is proportional to the local stress. Therefore, the stress of every location can be found by analyzing the light intensity of the patterns

$$g^2 = \frac{1}{4}\sum_{i,j}\left[\left(\frac{I(i+1,j)-I(i-1,j)}{2}\right)^2 + \left(\frac{I(i,j+1)-I(i,j-1)}{2}\right)^2 + \left(\frac{I(i+1,j+1)-I(i-1,j-1)}{2\sqrt{2}}\right)^2 + \left(\frac{I(i+1,j-1)-I(i-1,j+1)}{2\sqrt{2}}\right)^2\right]$$

Results

Single Compressed Particle



In the process of compressing a particle, the number of fringe pattern increases and the g^2 also grows. That is, as the force exerted on the particle becomes larger, there will be more fringe patterns.

Fig.1 local stress vs time of single compressed particle

One Dimensional Compressed Particles

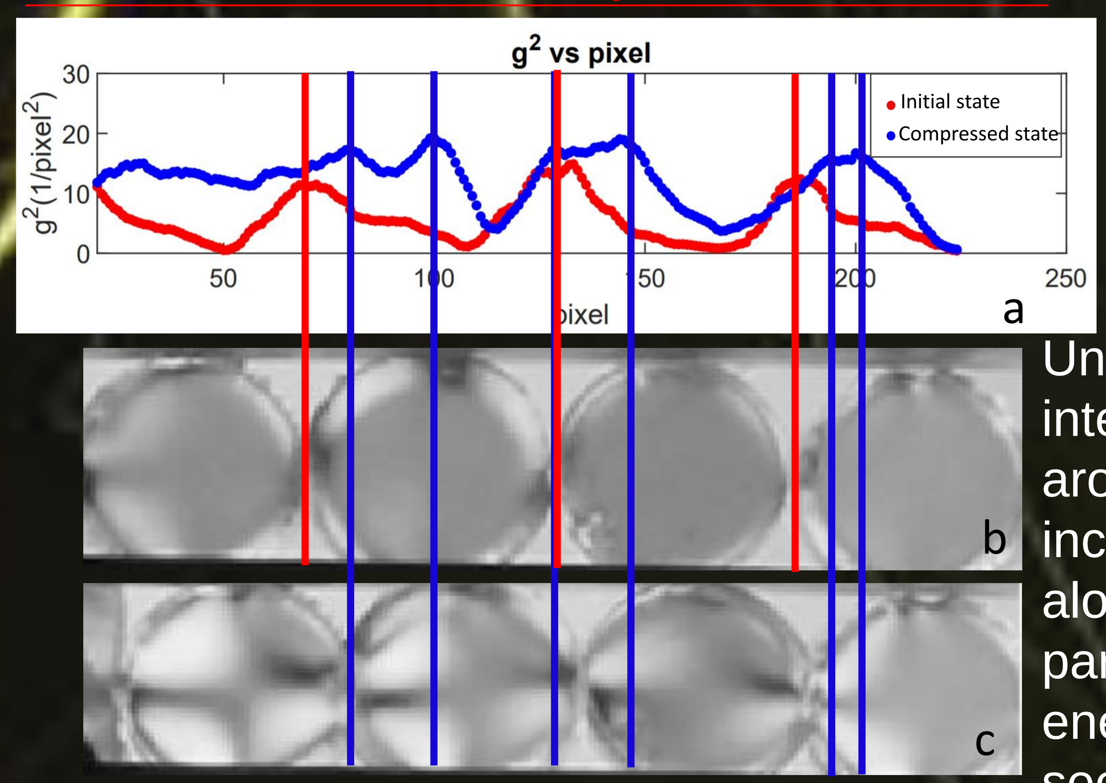
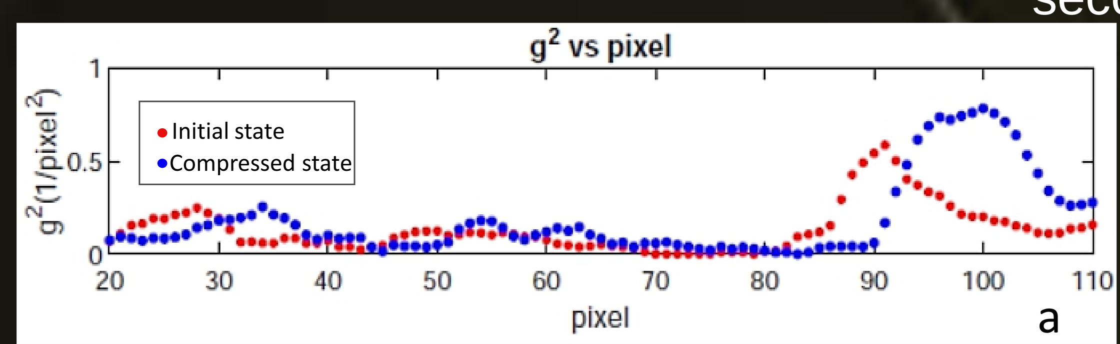


Fig.2 (a) g^2 vs pixel of circular particles in one dimensional compression (b) initial state (c) compressed state

Under the compression, the light intensity changes obviously around the edge, and g^2 increases . The force decays along the transition from a particle to the next one. The energy dispassion from the second particle.



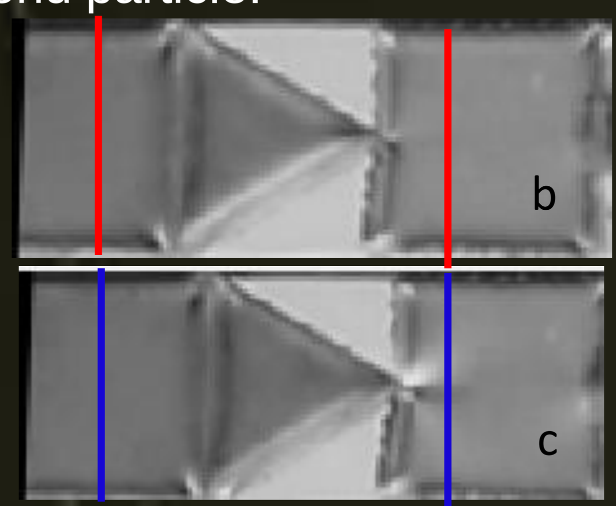
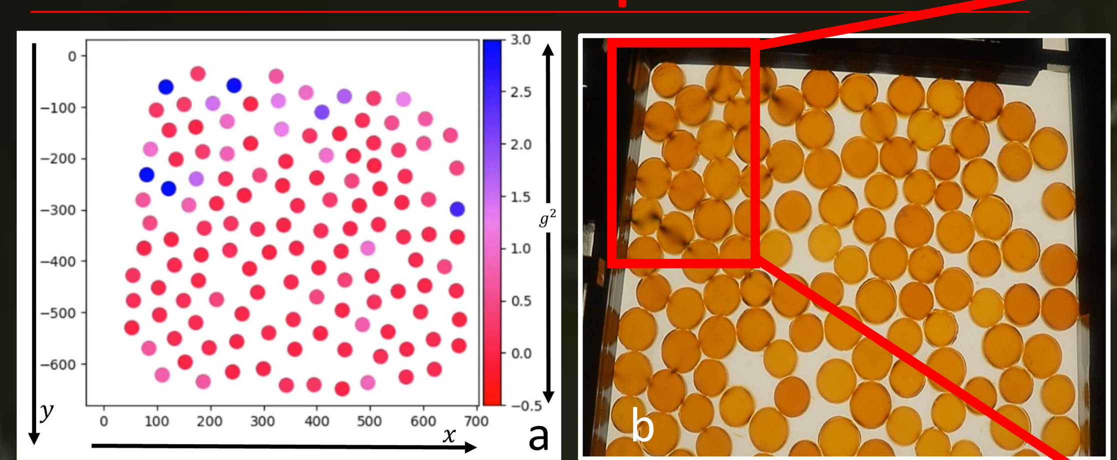
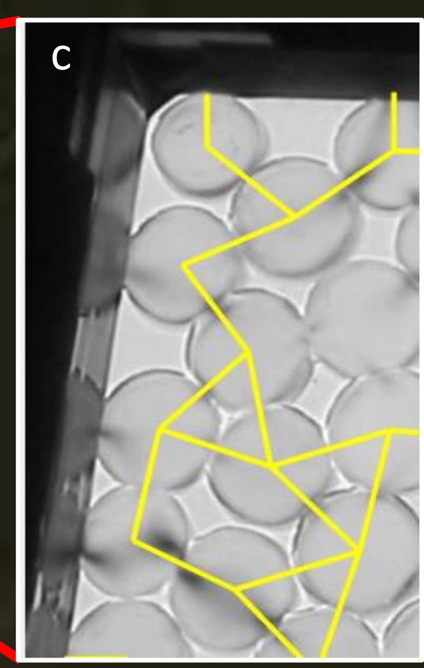


Fig.3 (a) g^2 vs pixel of point and plane contact in one dimensional compression (b) initial state (c) compressed state

In Fig.3(a), the plateau can be seen during the compression, and this obvious change of the fringe pattern is seen on the contact point between the sharp corner of the triangle and the side of the square. Therefore, a square and a triangle particle can be considered as a whole.

Two Dimensional Compressed Particle





The magnitude of the stress in 2D system is larger around the moving sides in the compressed process. After detecting the distance between two particles, we analyzed the magnitude of g^2 on the connecting particles. Then, the effective force chains can be found.

Fig.4 (a) $g^2$of whole system (b) Particles around the moving sides (c) Force chains

Conclusion

- The stress increases with the number of fringe strips growing.
- In the process of force transmitting, the energy dispassion happens.
- The stress change of the point contact is obvious than the plane contact. Therefore, a square and a triangle particle can be considered as the same system.

References

[1] https://www.microscopyu.com
[2] M. M. Frocht, Photoelasticity 1st Edition, Published in 1963
[3] https://www.fxsolver.com
[4] Y.Zhao, H.Zheng, New Journal of Physics, 21, 023009 (2019)