From cracking to curling in drying colloidal films with varying water content

Weipeng Meng,† Mingchao Liu,† Yixiang Gan,‡ and C.Q. Chen†,1

†Department of Engineering Mechanics, CNMM & AML, Tsinghua University, Beijing 100084, China

‡School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia

Corresponding author's E-mail: chencq@tsinghua.edu.cn

Extended Abstract

Drying induced cracking in colloidal films is of fundamental interest in nature and various industrial applications. The cracking morphologies are in varied forms from the planet surface to the oil painting. A lot of industrial raw materials come in the granular form, and are used to mix with the liquid. For all the above, the first thing is to understand the details of the desiccation procedure. Evaporation from porous media is a complex pore scale transport process, which can be affected by many factors such as temperature, liquid phase distribution, the scales of the particles. Especially, evaporation from soil affects energy balance, land surface-atmosphere interactions. It is known that the crack patterns are the signature of the particles, solvent and substrate type, the drying conditions and the film thickness. Lazarus(2011) studied the influence of layer thickness on the crack patterns induced by desiccation, and found that the crack patterns can vary from craquelures to spiral with different thickness. Smith(2011) performed experiments on compliant elastomer surfaces in which the level of constraint was varied by changing the substrate modulus and gave a theory to describe the substrate modulus dependence of the cracking length scale. Lucas(2016) investigated how a substrate's shape affects the appearance of cracks above it by preparing mud cracks over sinusoidally varing surfaces and found that the observed crack patterns changed from wavy to ladder-like to isotropic as the thickness of the cracking layer increased. Shokri(2015) found that the crack spacing could be changed by putting salt into the colloidal film, and the crack spacing had a positive correlation with salt concentration. However, the effect of water content on the crack pattern induced by desiccation has yet to be quantified.

In this work, we report an experimental study on the effect of water content on the crack pattern in drying colloidal films. It is shown that water content has a significant effect on the crack formation in the drying colloidal films, resulting in transition of the failure pattern from random cracking to curling for different water contents. In this work, bentonite clay was dried over rigid circular glass substrate which was flat and smooth and had a diameter of 110mm. Slurries of bentonite were prepared by mixing a set weight of bentonite powder with a set of mass ratio of water. Slurries were then stirred until smooth and immediately poured evenly into the discs. In these concentrations the slurries behaved as fluids, from which we could ignore the memory effect. Then we put the discs with bentonite slurries on the heating plate which had a constant temperature of 40℃. The slurry would be dried totally after 6-12 hours, depending on the amount of water. Then we could get the crack patterns of different film thickness and different water content.

The results are showed in figure 1. In figure 1, each row shows the crack pattern's change with different water content and fixed weight of bentonite. And each column shows the crack pattern's change with a fixed water content but different weight of bentonite. From the result of the experiment, we can see that when the weight of bentonite is fixed, the mass of water can have a big influence on the final crack pattern. From the experiment, we can find that there is a critical water content above which the crack pattern can transform from random cracking to curling. In this experiment, the critical water content is 4:1(which means the ratio of the weight of water to the weight of bentonite is 4:1). Below the critical water content, the film tend to crack randomly. Above the critical water content, the film curls with the advent of several main cracks. It is also found that the critical water content depends on the film thickness. The film thickness is larger, the critical water content will also increase.

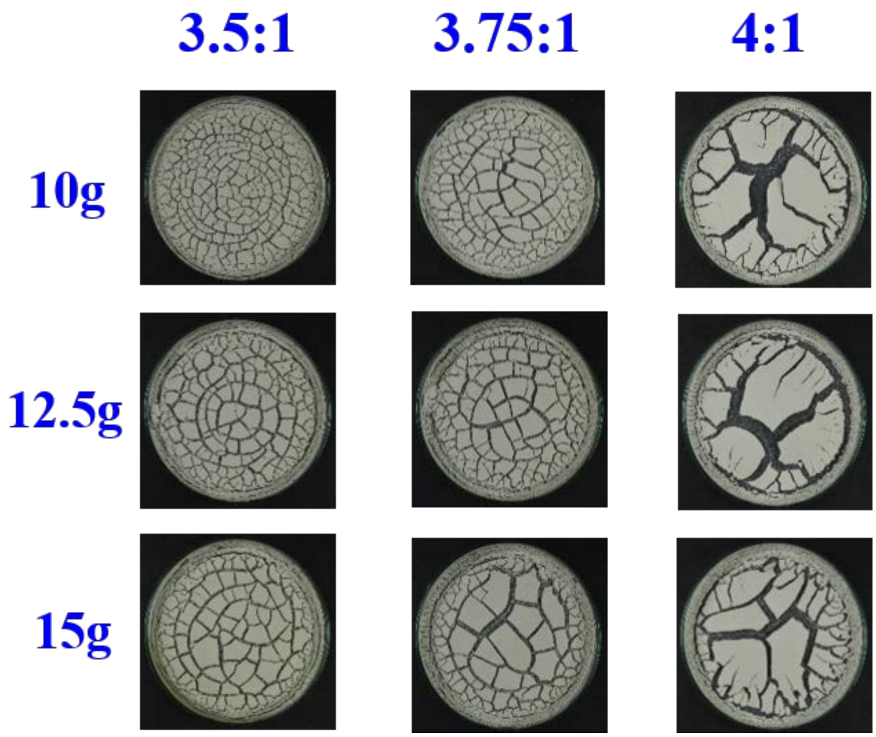

Figure 1. Crack patterns of the drying film with different weight of solid and different mass of water

We also performed a different experiment to give an evidence about why the water content can influence the crack pattern. When the weight ratio of water to bentonite is 5.5:1 initially, we stirred the slurry at the weight ratio of 3.5:1 during desiccation. Finally, we found that this crack pattern was almost the same as the crack pattern of initial ratio of 3.5:1. We can know that the crack pattern has a close connection with the initial weight ratio of water to bentonite.

Our results explore the effects of water content on crack patterns of thin films. We showed that the bentonite films have a critical water content after desiccation. As the water content increases, the crack pattern will transform from random cracking to curling. This phenomenon is caused by the initial water content directly. We proposed a gradient water content model to explain these experimental results. It will be discussed in detail in the full paper.

REFERENCES

Smith, M. I., & Sharp, J. S. (2011). Effects of substrate constraint on crack pattern formation in thin films of colloidal polystyrene particles. Langmuir, 27(13), 8009-8017.

Lazarus, V., & Pauchard, L. (2011). From craquelures to spiral crack patterns: influence of layer thickness on the crack patterns induced by desiccation. Soft Matter, 7(6), 2552-2559.

Nandakishore, P., & Goehring, L. (2016). Crack patterns over uneven substrates. Soft matter, 12(8), 2253-2263.

Shokri, N., Zhou, P., & Keshmiri, A. (2015). Patterns of desiccation cracks in saline bentonite layers. Transport in Porous Media, 110(2), 333-344.