Applied Clay Science 86 (2013) 125–128

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

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Crack formation in Laponite gel under AC fields

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ARTICLE INFO

Article history:
Received 19 August 2013
Accepted 25 September 2013
Available online 17 October 2013

Keywords:
Crack formation
AC field
Crack bending
Laponite

ABSTRACT

Crack formation patterns in Laponite gel are known to be strongly affected by electric fields produced by a DC (direct current) source. It can be shown that AC (alternating current) fields produce equally remarkable patterns in a radially symmetric set-up. The character of the pattern depends crucially on the field strength. A significant feature observed is the bending of radial cracks, with the curvature increasing as field strength is increased. Voltages of 20 to 70 V have been applied and several features of the resulting patterns quantified. Striations on the fracture surfaces and crack speeds are also studied.

1. Introduction

The importance of the study of desiccation cracks and fracture growth as an interdisciplinary field is widely accepted, as evident from the considerable literature being published in journals of physics, geology, mechanical and chemical engineering and mathematics. More recently it has been realized that crack patterns can be controlled and tailored to produce 'designer cracks' which may be useful in nanofabrication (Nam et al., 2012) and manufacture of surfaces with special texture. Exposure to electric fields may be one of the methods for controlling fracture. Formation of desiccation crack patterns in the synthetic clay mineral — Laponite, is strongly affected by the presence of an electric field (Khatun et al., 2012; Mal et al., 2008). It is shown here that alternating (AC) fields produce equally remarkable effects. Clay particles are charged in aqueous environment (van Olphen, 1977), so response to an electric field is quite natural. The effect of electric fields on mechanical fracture in dielectric materials was reported much earlier (Suo, 1993), in particular an AC field seemed to favour crack growth normal to the field direction (Cao and Evans, 1994).

In the present communication, preliminary results on the effect of radially symmetric AC fields of varying strength, on a Laponite gel dried in a circular polypropylene petri-dish of 10 cm diameter are reported. As the field strength is increased from 20 V to 70 V AC (50 Hz), the pattern of cracks undergoes a remarkable series of changes which are quite reproducible.

2. Experimental

Laponite RD (Rockwood additives), deionized water and crystal violet dye are the necessary ingredients. To prepare the solution a digital weighing machine, measuring cylinder, beaker, spatula and a magnetic stirrer are required. A polypropylene petri-dish is used as the substrate. The setup is similar to the earlier studies (Khatun et al., 2012). Aluminium foils are used to make the electrodes, one in the form of a thin rod and another in the form of a short cylinder. A variac is needed to apply different AC voltages (V_{AC}s) from the main supply (240 V, 50 Hz) to the sample. A digital camera (Nikon Coolpix) is used for photographing the patterns.

The rod like electrode is placed at the centre of the petri-dish and the short cylindrical electrode is fitted along the inner periphery as counter-electrode. In the present experiments 2.5 g of Laponite (Rockwood additives) is added to 40 ml of distilled water containing a trace of crystal violet dye (to make the cracks easily visible), while stirring on a magnetic stirrer. The mixture is stirred for 20–30 s and poured in the circular petri-dish of 10 cm diameter fitted with two electrodes. After waiting for 5 min till the solution spreads out evenly and gels, a variac is used to apply an AC field between the two electrodes while the gel is allowed to dry. The formation of crack patterns has been studied for different AC voltages (V_{AC}s) (in the range 20 V–70 V).

3. Results and discussion

Fig. 1(a–c) shows typical patterns for 20 V, 40 V and 60 V applied to the sample, during drying. For relatively lower voltages (V_{AC} = 20 V, 25 V), cracks start to appear at the periphery ~85–90 min after the field is turned on. But interestingly, they do not proceed radially towards the centre, rather they curve, forming a nearly circular pattern

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0169-1317/$ – see front matter
http://dx.doi.org/10.1016/j.clay.2013.09.012

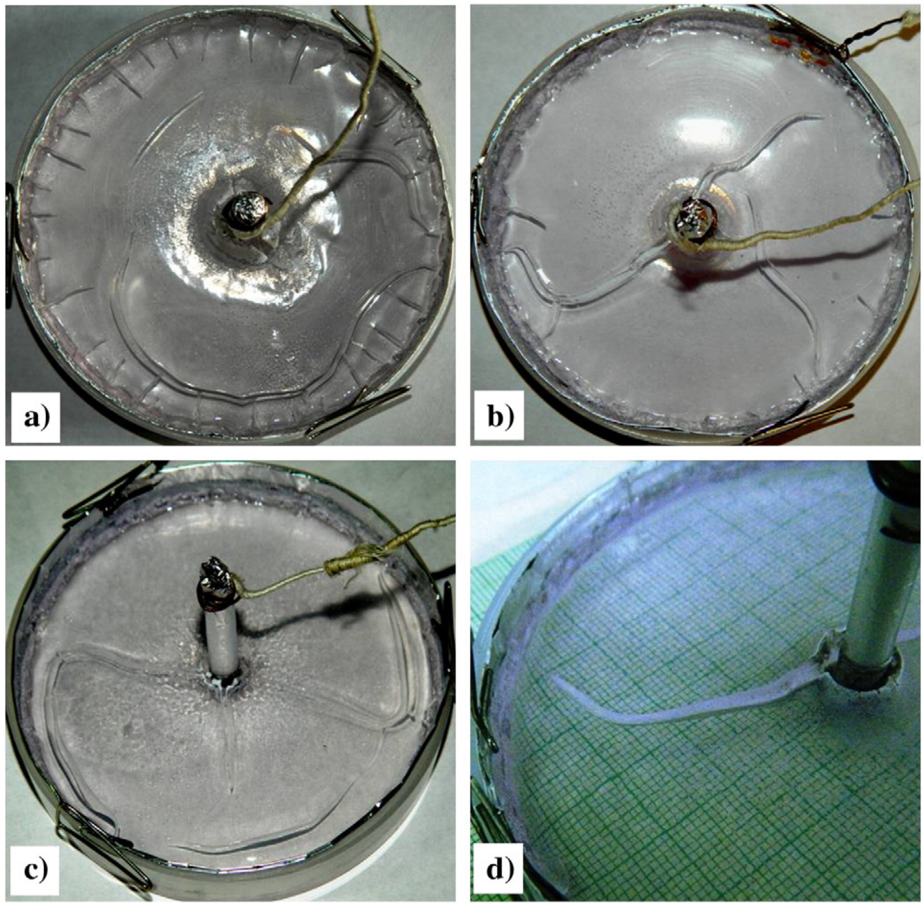

Fig. 1. Figures a, b, c and d show respectively, the crack patterns of 20 V, 40 V, 60 V and the close-up view of a crack with curvature (at 30 V, after 4 h 52 min). They are not the final patterns but taken when the typical characteristics are best visible, for a, b and c the snapshots are taken after 22 h 47 min, 23 h 26 min and 7 h 11 min respectively. In (a) cracks start to form first from peripheral electrode and some cracks appear from central electrode at a later time. In b and c cracks start to appear from central electrode first and then from outer electrode.

along the boundary. At a later time some cracks also form from the central electrode. As the voltage is increased to 30 V or higher, cracks appear initially from the centre, in addition to some from the periphery at a later time. Those from the centre do not however, run straight in the radial direction, but tend to curve around. The curvature increases with the applied voltage. A close-up of the curved crack is shown in Fig. 1(d). It could not be possible to go higher than 70 V, due to sparking near the central electrode.

3.1. Quantification of observations

To quantify the results several measurements have been performed. (1) The number of cracks at the inner and outer electrodes, (2) the time of first crack appearance, (t_a) and (3) the radius of curvature (R_c) of the curving cracks from the centre, all as functions of the applied AC voltage (V_{AC}). In some cases (4) the average speed of crack propagation has been measured. Another aspect of the *dynamics* of crack propagation is studied as well. Since the Laponite gel is transparent, the crack tip opening and its motion can be photographed quite clearly. Thus, the direction of crack motion can be compared with the direction of parallel striation marks left on the fracture surface after the cracking process completes.

3.1.1. Crack numbers at both the electrodes

Fig. 2(a) shows plots of the number of cracks counted at the outer boundary — N_{out} and the number counted at the central electrode — N_{in} against the AC voltage (V_{AC}). Out of these cracks some did not originate at the respective electrode, but have arrived there from some other points of the sample, omitting these, the cracks which *originate* at the outer or inner boundary are counted. These are labelled as $N(O)_{out}$ and $N(O)_{in}$ and shown separately on the graph. It is seen that the number of cracks at the outer electrode first falls with V_{AC} and then increases again with a minimum near $V_{AC} = 40$ V. The number at the inner electrode is much lower ~4–6, compared to ~12–32 at the outer and varies very little with V_{AC}.

3.1.2. Time of first crack appearance (t_a)

At $V_{AC} = 20$ V it takes ~87 min for the first crack to appear. As V_{AC} increases, the time of first crack appearance t_a decreases rapidly at first, then slower and at 70 V, it becomes ~2 min. This is shown in Fig. 2(b).

3.1.3. Radius of curvature (R_c) of the curving cracks

At higher V_{AC}, the cracks starting from the centre bend around, the curvature increases with V_{AC} and the distance from the central electrode, where the crack starts to curve decreases. The radius of curvature (R_c) is approximated by fitting a circle at the point where the curvature is strongest. Fig. 3 shows how R_c varies with V_{AC} and the method of determining R_c is shown in the inset. Results for the 3 sets shown are observed under different ambient conditions. For set 1 — temperature is in the range of 30 °C–32 °C and relative humidity is 45%–64%, for sets 2 and 3 these are 22 °C–26 °C, 45%–60% and 26 °C–29 °C, 35%–44.

3.1.4. Crack front and striation marks on the fracture surface

A snapshot of a crack tip during growth is shown in Fig. 4(a1). The shape of the front clearly shows that this crack initiates and continues to grow along the upper surface of the Laponite layer. Fig. 4(a2) shows the fracture surface of the same crack in Fig. 4(a1) after it has grown completely and intersected the larger crack seen on the left of Fig. 4(a1). The gelled material on the other side of the crack has been