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Desiccation crack initiation and propagation in clay with MgO

Rui Qi[1], Sérgio D.N. Lourenço[2] and Antonios Kanellopoulos[3]

[1]PhD Student, The University of Hong Kong, Hong Kong S.A.R., China, email: ruiqi000@connect.hku.hk

[2]Associate Professor, The University of Hong Kong, Hong Kong S.A.R., China, email: lourenco@hku.hk

[3]Associate Professor, University of Hertfordshire, Hertfordshire, UK, email: a.kanellopoulos@herts.ac.uk

ABSTRACT

As a natural phenomenon in near-surface soils, desiccation cracks are affected by various factors including clay type and water content. In this study, the effect of Magnesium Oxide (MgO) addictive on soil hydraulic and cracking properties was investigated. The effect of MgO and MgO content on the desiccation cracking of kaolinite clay was conducted with laboratory tests. The water content and the water evaporation rate were measured during drying. The result shows that the MgO addictive decreased the water evaporation of clay. A digital image-capturing system was applied to analyse the cracks propagation and features during desiccation. The results demonstrate a significant influence of MgO on the cracking behaviour of kaolinite clay subject to desiccation. The addition of the MgO increased the number of cracking segments, cracking length per unit area, and cracking area. However, there was a reduction of the cracking width with the addition of MgO. Moreover, with the increase of MgO content in the soil, more cracking was generated. This research provides insight into the desiccation process of clay containing MgO with respect to water evaporation, shrinkage, and cracking.

Keywords: Desiccation cracks, Kaolinite, Clay, MgO

1 INTRODUCTION

Desiccation cracking is a common natural phenomenon in near-surface soils, which is induced by drying (Tang et al., 2021). In recent years, more frequent occurrences of extreme weather lead to an increase of desiccation and subsidence related hazards (Tang et al., 2021). Past results show that desiccation cracks weakened soil strength, increased the compressibility (Albrecht & Benson, 2001; Morris et al., 1992) and the vertical permeability of clay. Desiccation cracks are usually taken as an undesirable factor in agriculture, architecture, and transportation infrastructure (Shepidchenko et al., 2020). However, In the area of the petroleum industry, the generated cracks provide migration conduits and accumulation spaces for natural gas and formation water and thus contribute to the gas accumulation and production (Ding et al., 2012).

Desiccation cracking of clay is a complex process influenced by various factors. Past research shows that the desiccation cracking of clay is closely related to its mineral composition. Smectite typically adsorbs more water and undergoes greater shrinkage, while illite, kaolinite, and quartz induced smaller shrinkage strains in soils (Albrecht & Benson, 2001). Soil that contained montmorillonite exhibited higher volumetric deformation because the montmorillonite induced strong hydrophilicity in soils compared to other minerals (G. Omidi et al., 1996). The desiccation cracking is also affected by the salinity of soils, more specifically, Lima and Grismer (1992) found that with increasing salinity in soils, the crack depth decreased but the crack area and crack volume increased. The type of ions also affects soil cracking. Increasing the concentration of K^+ and Na^+ reduced the cracking while increasing the concentration of Mg^{2+} increased the extent of the cracking (Xing et al., 2016).

Additives including cement, lime, and fly ash have been used in clay to evaluate their effect on soil desiccation cracking. The results show that these calcium-based additives enhanced the soil structure and reduced the shrinkage potential (Al-Taie et al., 2016; Kolias et al., 2005).

Magnesium Oxide (MgO) can be produced by calcining magnesite and applied as an expansion agent in concrete (Wang et al., 2022). With the addition of MgO, the drying shrinkage of concrete was reduced and the microcracks in concrete were sealed samples after 28 days of healing (Guo et al., 2021; Qureshi & Al-Tabbaa, 2016). So far, the effect of MgO on the shrinkage and cracking property of clay stll has not been investigate.

This research aims to evaluate the effect of MgO additives on the cracking behaviour of clay. Specific objectives are (1) to study the influence of MgO additives on the water evaporation process of clay during drying, (2) to quantify the effect of MgO on crack propagation and features (the number of crack segments, crack length per unit area, crack width, and crack area) during drying, and (3) to investigate the influence of MgO content on the soil desiccation cracking. The results will elucidate the desiccation process of clay containing MgO with respect to water evaporation, shrinkage, and cracking.

2 METHODS

2.1 Material

Kaolinite clay was used in this investigation. Kaolinite is a common clay in soils derived from igneous rocks. Various works have been done to study the desiccation cracking formation of kaolinite (Shepidchenko et al., 2020; Tabassum & Bheemasetti, 2020; Wei et al., 2016). MgO was purchased from Sigma Aldrich.

2.2 Test methods

Testing was carried out in a series of steps: (1) Slurry preparation. A slurry was prepared by mixing clay, MgO, and distilled water at different MgO contents (0%, 2%, and 5% by dry weight of the soil). The initial water content was around 150%. (2) Specimen preparation. The obtained slurry was poured into petri dishes (120mm in diameter) and placed in a vibrator for 5 minutes to remove the trapped air bubbles in the slurry. The initial thickness of the specimens was 8 mm leading to an aspect ratio of 15. Similar aspect ratios have been produced in the past in order to produce a distinguishable crack pattern (Chaduvula et al., 2017). Past analysis showed that no macroscopic cracks will produce in the material if the aspect ratio is smaller than 5.8 (Colina & Roux, 2000). (3) Drying and image capture. The prepared specimens were dried at room temperature (25 ± 1 ° C, 60 ± 5% RH). As shown in Figure 1, the sample was weighed during the drying process to record the moisture loss. Digital cameras were fixed above the specimen to monitor crack propagation. (4) Image analysis. The captured cracking images were analyzed with *ImageJ* and the cracking features were calculated. Two replicates have been done for each test. The parallel specimens were prepared and dried in the same condition.

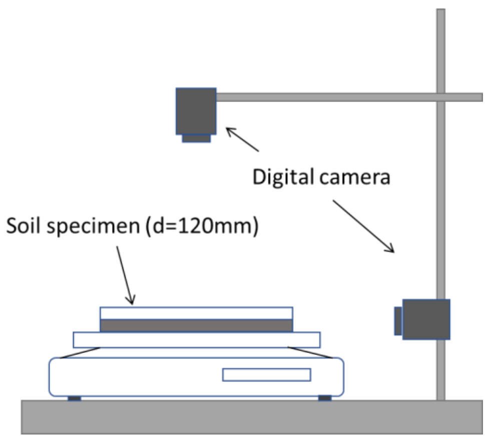

Figure 1. *Schematic drawing of the experimental set-up.*

3 RESULTS AND DISCUSSION

3.1 Water evaporation

The water evaporation process, as a consequence of drying, was measured. Figure 2 (a) and (b) show the change of water content *w* and water evaporation rate R_e during drying. The water evaporation process was divided into two stages based on the water evaporation rate. In the first stage, the water evaporation rate was constant (approximately 1.1g/h), and the water content decreased linearly. In the second stage, the water evaporation rate decreased to zero after 1000 mins with the water content stabilizing at around 4%. With the increase of MgO content in clay, the water content in the stable stage increased, and the water evaporation rate during drying decreased. A possible reason is the hydration of MgO, which produced $Mg(OH)_2$, retaining water in clay and decreasing the water evaporation.

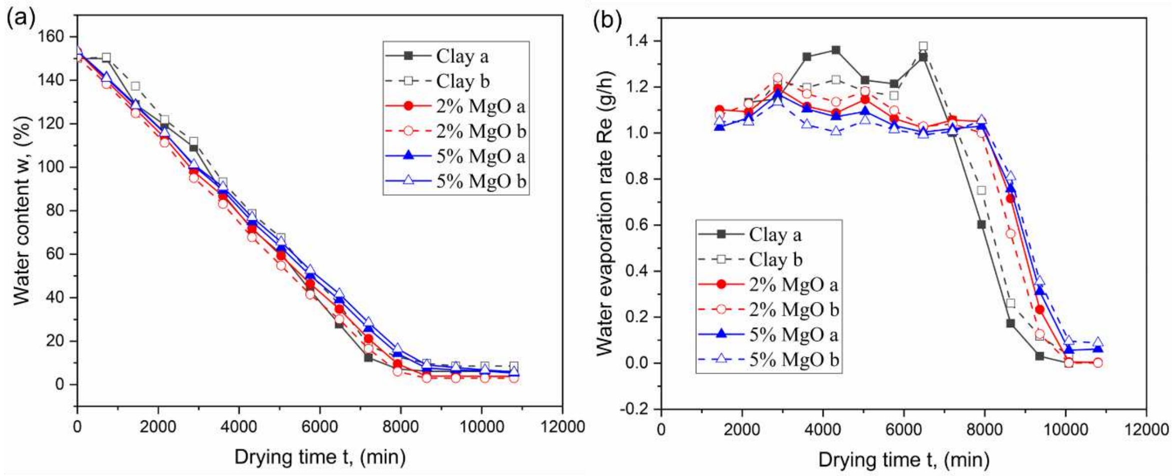

Figure 2. *Desiccation curves of kaolinite with MgO during drying: (a) water content, (b) water evaporation rate.*

3.2 Crack features measurements

The crack features (the number of crack segments, crack length per unit area, crack width, and crack area) during drying was measured and shown in Figure 3. There is no crack formed with drying in the initial stage. Cracks started forming at given water contents, and the crack parameters (the number of crack segments, crack length per unit area, crack width, and crack area) increased with the decrease of water content. In the final stage, no more cracks were formed, with cracking reaching a stable stage.

The addition of MgO affected the water content at which cracks started to form. As shown in Figure 3, cracks initiated earlier (at a higher water content) when MgO was added to the clay. During drying, the corresponding water content when the first crack is observed on the specimen surface is defined as the cracking water content (Tang et al., 2011). For kaolinite clay, the average cracking water content was 40.06% while for clay mixed with 2% and 5 % MgO, the average cracking water content increased to 83.88% and 90.11%.

The addition of MgO increased the number of crack segments in the final stage. Figure 3 (a) shows the number of crack segments increasing with drying and then stabilizing. The average number of crack segments for clay was 11.5 in the final stage while for clay mixed with 2% MgO and 5% MgO, the number increased to 17 and 21.5, respectively. The change of crack length per unit area during drying is shown in Figure 3 (b). The crack length per unit area increased after the start of cracking. After completion of cracking, the average crack length per unit area was 1.73, 1.95, and 2.09 mm/cm^2 for clay, clay mixed with 2% MgO, and 5% MgO, respectively. Figure 3 (c) shows the change of average crack width during drying. The average crack width of clay, clay mixed with 2% MgO, and 5% MgO after cracking were 0.69 mm, 0.73 mm, and 0.75 mm, respectively. It indicated that there was a increase for the cracking width when the MgO was mixed into the clay. The crack area during drying is shown in Figure 3 (d). With the increase of MgO content in clay, the crack area increased during drying. When the crack development stabilised, the crack area increased from 534.1mm^2 (clay) to 651.1mm^2 (2% MgO addition), and 703.6mm^2 (5% MgO addition).

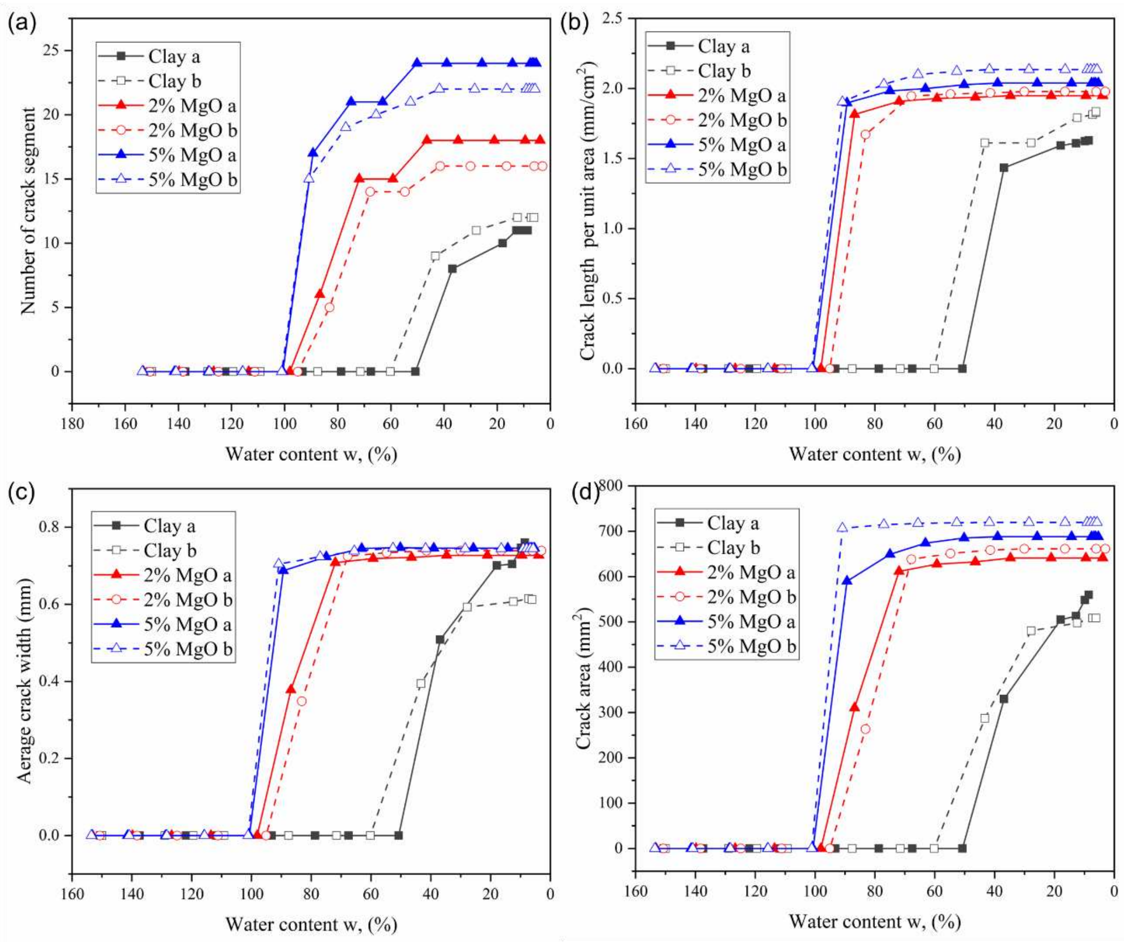

Figure 3. *Cracking features during desiccation: (a) number of crack segments, (b) crack lengths per unit area, (c) average crack width, (d) crack area.*

3.3 Crack propagation

Past studies investigated the crack propagation of clay. The results showed that an internally generated crack tends to propagate from both of its ends until it intersects another crack. The edge-generated cracks would propagate at mostly right angles perpendicular to the existing crack due to the stress relief (Morris et al., 1992). Figure 4 shows the crack propagation for clay, clay mixed with 2% MgO, and clay mixed with 5% MgO. The addition of MgO increased the number of cracking. With increase of MgO content in soil, more axial edge cracks were generated, which indicated a larger shrinkage strain of the samples.

Past research showed a prominent effect of cement addition on the drying shrinkage of highly expansive clay soils. The addition of 3% cement reduced shrinkage by up to 50% (G. H. Omidi et al., 1996). However, soil desiccation cracks could not be suppressed with lime or cement additives when the initial water content was high (G. H. Omidi et al., 1996). The soil samples in this test had an initial water content of 150%, which can be considered high and may explain the detrimental effect of MgO addition on soil drying shrinkage.

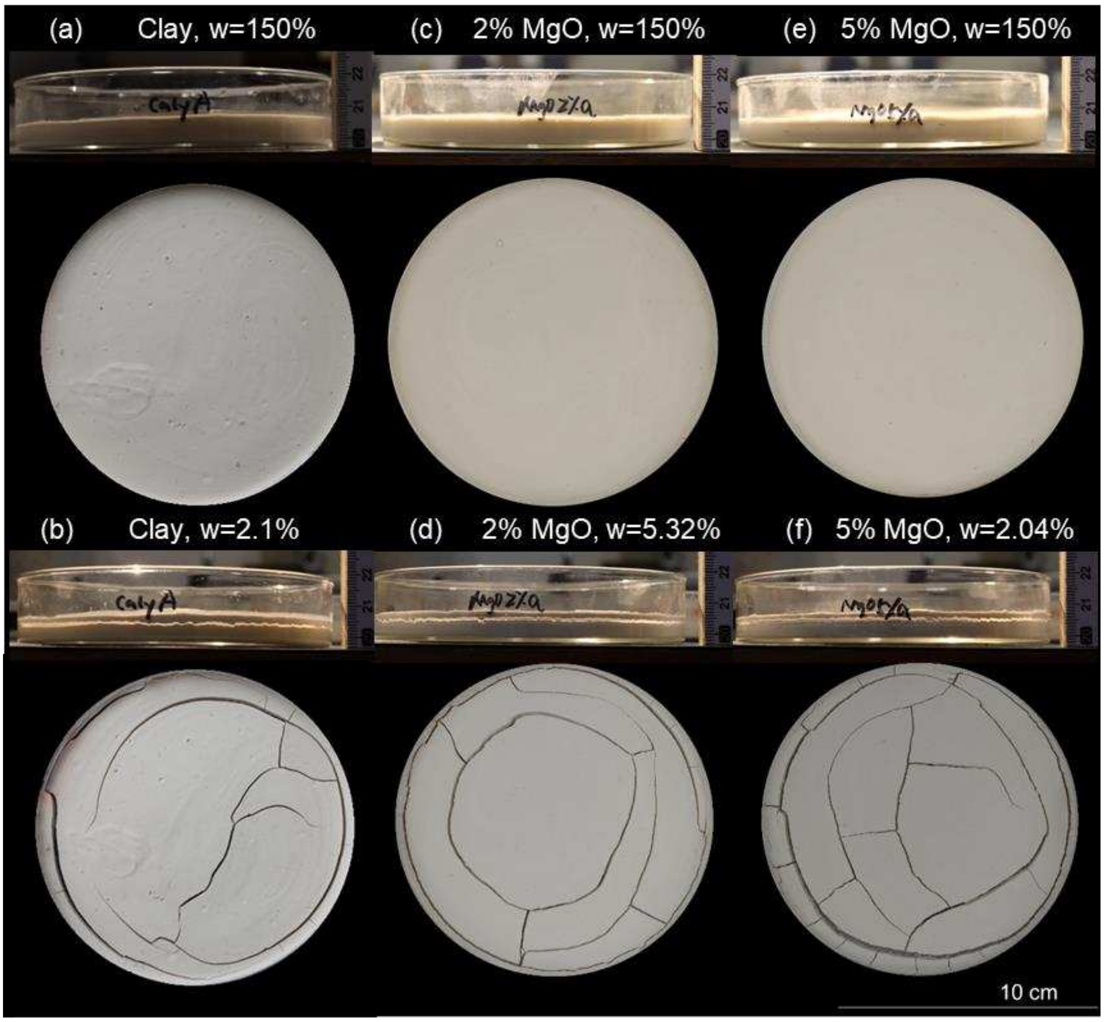

Figure 4. *Desiccation crack propagation of: (a)(b) clay, (c)(d) clay mixed with 2% MgO, and (e)(f) clay mixed with 5% MgO (petri dish diameter = 120 mm).*

4 CONCLUSIONS AND FUTURE WORK

Laboratory tests were performed on kaolinite with different contents of MgO. With the investigation on the hydraulic and cracking features of clay with and without MgO additive, the following conclusions can be drawn: (1) The addition of MgO decreased its water evaporation rate. (2) MgO increased the water content at which the cracks started to form, which indicated that cracking generated earlier than that without MgO. (3) A significant change in the cracking pattern of kaolinite is observed with MgO addition. The increase of MgO content in clay induced more cracking during desiccation in kaolinite. After desiccation, the cracking features including the number of crack segments, crack length, the average cracking width, and crack area increased with MgO addition. Unlike cementitious materials where the benefits of MgO are proven, overall, this preliminary study suggests that the addition of MgO in clays is unlikely to arrest crack development.

MgO-based expansive agents have been proven to mitigate shrinkage-induced cracking in concrete through the increased volume of produced hydration products or the crystallization pressure during the growth of the products (Lu et al., 2023). This study tested the desiccation crack initiation and propagation in kaolinite clay with MgO. Future work will evaluate the desiccation crack initiation and propagation in clays with other mineral compositions, such as smectite and illite. Additionally, further research will explore the potential of MgO-based expansive agents to prevent the initiation and propagation of cracks in cemented soils.

5 ACKNOWLEDGEMENTS

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