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Influence of water content and soil type on soil cracking

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ABSTRACT

Cracks are common in clayey or expansive soils. The presence of cracks in clayey or expansive soils can lead to problems related with the stability of soil slopes and the integrity of liners and covers. The cracking of soils is significantly affected by the water content of soils and the soil types. In this study a series of laboratory tests were conducted to investigate the influence of water content and soil type on soil cracking. Four soil specimens were prepared by mixing kaolin and montmorillonite with different proportions. Several drying-wetting cycles were applied on these soil specimens. When the crack development is stable the images of the cracked soil were taken using a digital camera. Then, a live-wire algorithm was used to extract the edges of the crack. Finally, the crack geometric parameters (i.e., average aperture, standard deviation, and scale of fluctuation) were obtained. The results show that the average aperture, standard deviation, and the scale of fluctuation of crack apertures demonstrate a significant three stages: initial stage, primary stage, and steady state stage. The results also show that the average aperture increases linearly with the increasing proportion of montemorillonite. The number of cracks increases initially with increasing montemorillonite and then decrease. This may be because the tension is relaxed when the crack aperture is large in soil specimens with more montmorillonite.

KEYWORDS: unsaturated soil, crack, desiccation, seepage, shrinkage

1. INTRODUCTION

Cracks are common in clayey or expansive soils and can increase the hydraulic conductivity of soils. The increase in hydraulic conductivity of soils can facilitate water infiltration and reduce the shear strength of soil (Li 2011c). It is well noted that cracks

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may lead to slope failures (Baker 1981, Lee 1988), dam failures (Talbot 1993, Xu 2009, Peng 2011), liner failures (Tay 2001) and foundation failures (Silvestri 1992).Therefore, the study of influence factors of crack development is potentially beneficial in many geotechnical projects.

Many factors can influence the development of soil cracking such as mineral composition, clay content, layer thickness and size, boundary conditions, wetting and drying cycles etc. (Mitchell 1993, Wahab 1995, Albrecht 2001, Nahlawi 2006). The development of desiccation cracks using small-size (usually a few centimeters thick) slurry, clay, or starch–water mixture cakes have been studied by many researchers (Shorlin 2000, Mizuguchi 2005, Kodikara 2006, Peron 2006). Their results, however, were significantly different with the compacted soils in engineering practice. Li and Zhang (2011b) conducted a field experiment on two soils to study the crack initiation and development. The relationships between crack geometrical parameters and water content were investigated. The results show that desiccation cracks developed in three stages. The crack formation and morphology with different directions of drying, sample sizes, and sample thicknesses have been investigated (Shorlin 2000, Peron 2006). However, the influence of water content and soil types on cracking of compacted soils is not well understood. In this study a series of laboratory tests were conducted to investigate the influence of water content and soil type on cracking of compacted soils.

2. MATERIALS

Kaolin consists of combined silica-alumina sheets which are held together tightly by hydrogen bonding. Montmorillonite has a basic structure consisting of a sheet of alumina octahedrons between and combined with two sheets of silica tetrahedrous. The space between the combined sheets is occupied by water molecules and exchangable cations. There is a very week bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being absorbed between the combined sheets. The kaolin and montmorillonite soils were mixed into four new soil specimens according to the weight proportions. The new soil specimens are shown in Table 1 and the properties of these soil specimens are shown in Table 2.

3. SAMPLE PREPARATIONS

First, kaolin and montmorillonite soils were dried to constant weight in the oven in the temperature range of 105 ~ 110 °C. Then, the kaolin and montmorillonite soils were weighed respectively according to Table 1 and then mixed uniformly. An electronic balance was used to get the weight of soil samples. The measuring range of the electronic balance is 150kg and the accuracy is 5g which guarantees the accuracy of the soil sample. Then soil materials with initial water content of 3% less than the optimum water content were prepared and placed in a plastic bag for 24 hours to ensure uniformly distributed water content. Finally, the soil materials were compacted to 94% standard compaction in containers. The metal container has a diameter of 500 mm and height of 350 mm. In this experiment, soil specimens were compacted to final height of 90mm in three layers.

4. EXPERIMENTAL PROCEDURE

In this section soil specimen I was used as an example to illustrate the experimental procedure. The soil parameters related with specimen I are shown in Table 3. The mass of the soil specimen was firstly measured. Then the picture of the soil specimen was taken before placing it in an oven. The initial state of the soil specimen is shown in Fig. 1. The oven temperature maintains a constant temperature of 33°C. Digital images were taken with minimized distortion by fixing the camera on a tripod and using a scale placed on the soil surface as a reference. The relative position of soil specimen and camera was ensured unchanged for every snapshot. The camera has effective pixels of 1.2-Megapixel and the accuracy of the picture is 0.105 mm.

The water content of the soil specimen decreased with time in the oven. The soil specimen was taken out from the oven every 2 hours. The mass of the soil specimen was measured and used to calculate the average water content of the soil specimen. The development of the cracks can be observed with decreasing water content. The cracks on the surface of the soil specimen were recorded by digital camera.

When the changes in water content were slow and the development of cracks tends to a stable condition, the drying process of the soil specimen came to an end. Then sufficient water was added to the soil specimen and saturated the specimen. Three drying and wetting cycles were conducted.

The pictures of the soil specimen were taken continuously during the three drying-wetting cycles and used to quantify the crack development. A live-wire algorithm (Li 2011a) was used to extract the edges of the crack from the pictures. The average aperture, standard deviation, and scale of fluctuation were calculated.

5. RESULTS AND DISCUSSIONS

5.1. Influence of water content

The geometric parameters of cracks were extracted at different water contents during the drying process. The stable condition of the crack development in the final cycle is shown in Fig. 2. A continuous opening along a certain direction in the soil is defined as a crack. There are eight cracks in the soil sample. The eight cracks form a network in the soil specimen.

The eight cracks were numbered as shown in Fig. 2. The next section will take the first crack as an example. The shape of this crack under different water content in the second drying process is shown in Fig. 3. The average crack aperture increase with decreasing water content. New cracks appeared at the middle of the crack when the water content was sufficiently low. The relationship between the water content and the average crack aperture is shown in Fig. 4.

Fig. 4 shows that the crack develops slowly when the water content decreases from 44.1% to 43.4%. When water content decreases from 43.4% to 33.3%, the development of crack is rapid. In this stage the average aperture of the crack developed from 2.7 mm to 6.1mm. The crack development tends to a stable condition when the water content is smaller than 33.3%. The average crack aperture slowly increased to 6.38 mm. The development of crack can be classified into three stages: initial stage, primary stage, and steady state stage. The reason for slow development at the initial stage is that the exposed surface of the specimen is only the surface soil of the specimen which is small. This results in a slow crack development with decreasing water content. When cracks are presented water can evaperate from both the surface of the soil specimen and the perimeter of the crack. As a result the crack development is sharp. When equilibrium is attained between the water content of the soil specimen and the environment, crack development is very slow and tends to a stable condition. The three stages are also observed in in-situ test by Li and Zhang (2011b).

The relationship between water content and standard deviation of the crack aperture is shown in Fig. 5. This figure shows that the standard deviation of the crack aperture increases with decreasing water content. The changes of the standard deviation also show three stages. When water content decrease from 43.4% to 39.2% the standard deviation of the crack aperture increase from 0.25 mm to 1.05 mm. When water content decreases from 39.2% to 33.3% the standard deviation increases from 1.05mm up to 10.17mm. When the water content values smaller than 33.3%, the standard deviation value changes slowly and tends to be stable. This result also indicates a three stage in crack development.

The aperture values at different locations are not statistically independent of one another in space. Knowing that an aperture at point (x_i,y_i) is above the average value suggests that the aperture at a nearby point (x_j,y_j) will also be above the average with high probability. This spatial structure variation can be described by spatial correlation. The spatial correlation is often expressed by scale of fluctuation, which measures the distance within which the aperture show strong correlation (Baecher 2003). If two points of the crack lie closer than its scale of fluctuation, the aperture values at these two points will be either higher or lower than the average aperture. The variation of scale of fluctuation with water content is shown in Fig. 6. It shows that the scale of fluctuation of crack aperture also experiences three stages. The reason is that the originally irrelevant data points become correlated when the cracks extend its length with the development of cracks.

5.2 Influence of montmorillonite

The proportion of montmorillonite affects the cracking of a soil significantly. In this study, four soil specimens (as shown in Table 1) with different proportion of montmorillonite were investigated. These specimens experienced two drying-wetting cycles and a stable condition is reached at the end. Fig. 7 shows the stable conditions of the four soil specimens. The number of cracks and the aperture of the cracks increase with the increasing proportion of montmorillonite.

Fig. 8 shows the variation of average aperture with the proportion of montmorillonite. The average aperture increases from 1.67 mm to 10.37 mm when the proportion of the montmorillonite increases from 30% to 60%. Fig. 9 shows the variation of the number of cracks with the proportion of the montmorillonite. The number of cracks increases with the proportion of the montmorillonite initially. However when the proportion of the montmorillonite is larger than 50%, the number of cracks decreases. This may be because the tension state is relaxed when the crack aperture is large in soil specimens with more montmorillonite.

CONCLUSIONS

Soil cracking process was intuitively observed through drying test on soil specimens. The development of the geometric parameters (average aperture, standard deviation, and scale of fluctuation) of the cracks during the drying process was obtained. The relationships between these crack geometric parameters and the water content were investigated. The influence of the proportion of montmorillonite on crack development was also analyzed. The conclusions are as following:

1. Crack development in soil samples show three stages: initial stage, primary stage, and steady state stage. The average aperture, standard deviation, and scale of fluctuation of the cracks are all have the three stages with the decreasing of water content in the soils.
2. The average crack aperture is gradually increased with the increasing in montmorillonite content. This is reasonable because the expansive ability is higher when the proportion of montmorillonite increases.
3. The number of cracks increases with the proportion of the montmorillonite initially. However when the proportion of the montmorillonite is larger than 50%, the number of cracks decreases.

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REFERENCES

Albrecht, B. A. and Benson C. H. (2001), “Effect of Desiccation on Compacted Clays”, *J. Geotech. Geoenviron. Eng., ASCE* **127**(1), 67-75.

Al Wahab, R. M. and El-Kedrah, M. A. (1995), "Using Fibers to Reduce Tension Cracks and Shrink/Swell in Compacted Clay", *Geoenvironment 2000, Y. B. Acar and D. E. Daniel, Eds., ASCE*, New York, N.Y., 791-805.

Baker, R. (1981), “Tensile strength, tension cracks, and stability of slopes”, Soils Found., **21** (2), 1–17.

Baecher, G.B. and Christian, J.T. (2003), “Reliability and statistics in geotechnical engineering”, *John Wiley and Sons Ltd*, England.

Kodikara, J.K. and Choi, X. (2006), "A simplified analytical model for desiccation cracking of clay layers in laboratory tests”, *Geotechnical Special Publication, No. 147. ASCE,* Reston, VA, 2558–2569.

Lee, F.H., Lo, K.W. and Lee, S.L. (1988), “Tension crack development in soils”, *J. Geotech. Eng.,* **114** (8), 915–929.

Li, J.H., Wang, Z.F. and Zhang, L.M. (2011a), “Spatial variability of aperture in a rough-walled crack in surface soil”, *GeoRisk 2011,* 287-294.

Li, J.H. and Zhang, L.M. (2011b), “Study of desiccation crack initiation and development at ground surface”, *Eng. Geol.*, 347-358.

Li, J.H., Zhang, L.M. and Li, X. (2011c), "Soil-water characteristic cure and permeability function for unsaturated cracked soil ", *Can. Geotech. J.,* **48**(7), 1010-1031.
Mitchell, J. K. (1993), *Fundamentals of Soil Behavior, John Wiley & Sons, Inc.,* New York, NY.
Mizuguchi, T., Nishimoto, A., Kitsunezaki, S., Yamazaki, Y., and Aoki, I. (2005), "Directional crack propagation of granular water systems", *Phys. Rev., E* **71** (5), 056122.
Nahlawi, H. and Kodikara, J.K. (2006), "Laboratory experiments on desiccation cracking of thin soil layers", *Geotech. Geol. Eng.,* **24**, 1641–1664.
Peron, H., Laloui, L., Hueckel, T. and Hu, L. (2006), "Experimental study of desiccation of soil", *Geotechnical Special Publication, No. 147. ASCE,* Reston, VA, 1073–1084.
Peng, M. and Zhang, L.M. (2011), "Breaching parameters of landslide dams, Landslides", doi:10.1007/s10346-011-0271-y.
Shorlin, K.A., de Bruyn, J.R., Graham, M. and Morris, S.W. (2000), "Development and geometry of isotropic and directional shrinkage-crack patterns", *Phys. Rev.,* E **61** (6), 6950–6957.
Silvestri, V., Sarkis, G., Bekkouche, N. and Soulie, M. (1992), "Evapotranspiration, trees and damage to foundations in sensitive clays", *Proceedings of the 43rd Canadian Geotechnical Conference, Part 2,* Quebec, Canada, Vol. 2, 533–538.
Talbot, J.R. and Deal, C.E. (1993), "Rehabilitation of cracked embankment dams", *Geotechnical Special Publication, No. 35. ASCE,* Reston, VA, 267–283.
Tay, Y.Y., Stewart, D.I. and Cousens, T.W. (2001), "Shrinkage and desiccation cracking in bentonite-sand landfill liners", *Eng. Geol.,* **60**, 263–274.
Xu, Y. and Zhang, L.M. (2009), "Breaching parameters of earth and rockfill dams", *J. Geotech. Geoenviron. Eng., ASCE,* **135** (12), 1957–1970.

Figures and Tables

Table 1 Percentage of montmorillonite and kaolin in different soil specimens

Soil specimen	Percentage of montmorillonite	Percentage of kaolin
I	30%	70%
II	40%	60%
III	50%	50%
IV	60%	40%

Table 2 Properties of different soil specimens

Soil specimen	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index	Optimum water content (%)	Maximum dry density (kg/m^3)
I	2.55	73.79	35.98	37.81	32.5	1300
II	2.53	77.27	35.43	41.84	32.9	1280
III	2.53	82.79	37.21	47.58	36.0	1260
IV	2.45	87.39	40.75	46.64	37.7	1230

Table 3 Properties for first soil specimen

Soil specimen	Mass (kg)	Volume (m^3)	Water content (%)	Dry density (kg/m^3)	Maximum dry density (kg/m^3)	Degree of compaction
I	27.955	0.017663	29.5	1220	1300	0.94

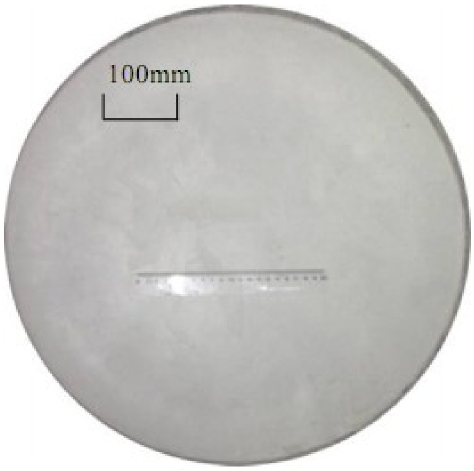


Fig. 1 Initial state of soil specimen I

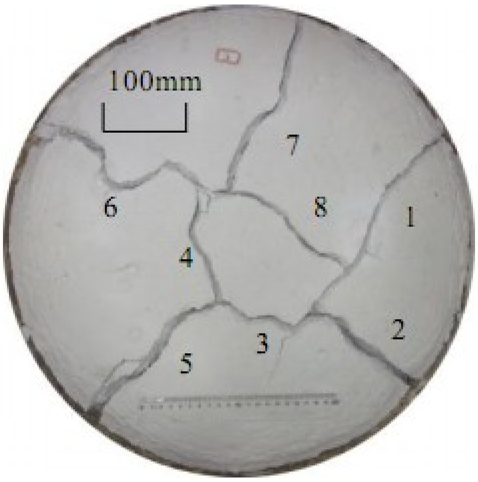
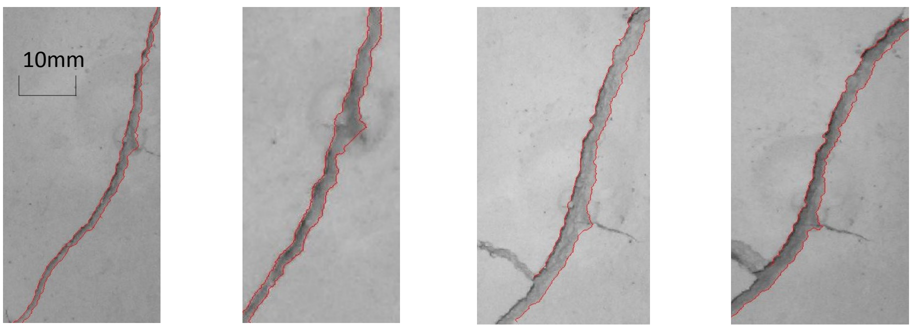


Fig. 2 Stable conditions of the crack and the number of cracks



(a) w = 43.4% (b) w = 39.2% (c) w = 37.7% (d) w = 10.2%

Fig. 3 Development of the first crack at different water contents

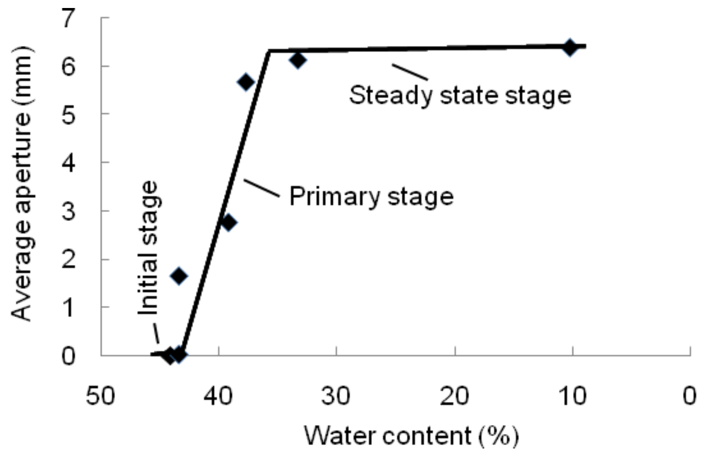


Fig. 4 Variation of average aperture with water content

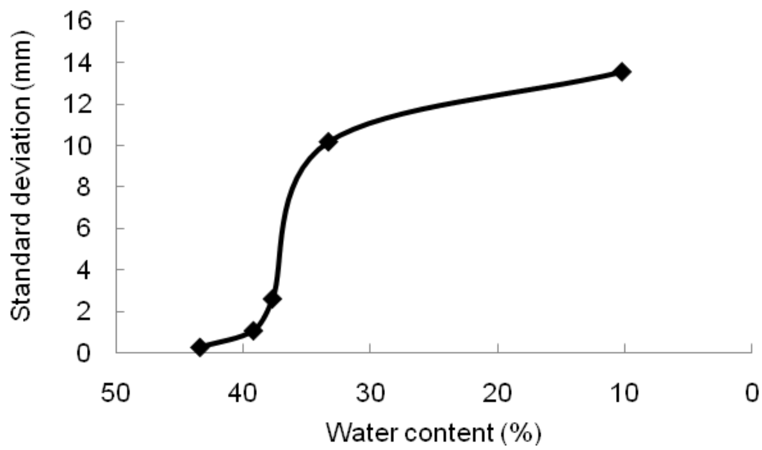


Fig. 5 Variation of standard deviation with water content

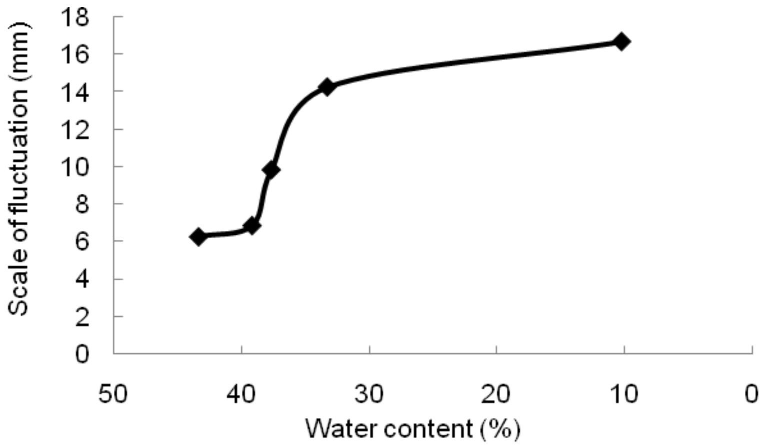
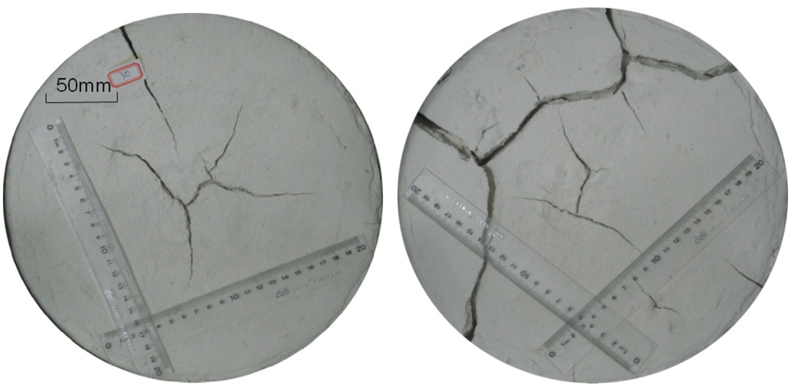


Fig. 6 Variation of scale of fluctuation with water content



(a) Specimen I (b) Specimen II

(c) Specimen III (d) Specimen IV

Fig. 7 Four cracked soils with different proportion of montmorillonite at steady state stage

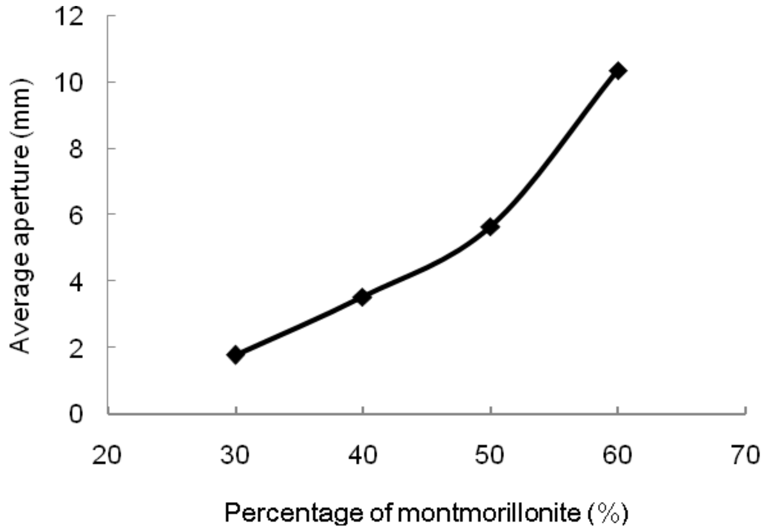


Fig. 8 Relationship between percentage of montmorillonite and the average crack aperture

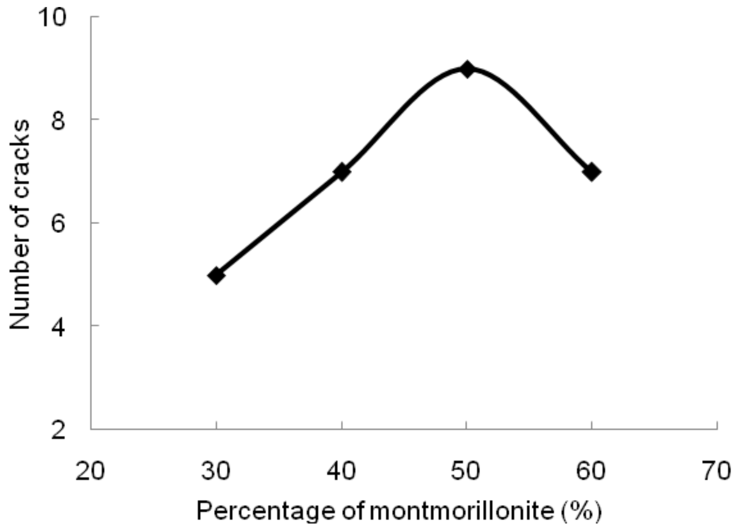


Fig. 9 Relationship between percentage of montmorillonite and the number of cracks