Australian Journal of Basic and Applied Sciences, 10(17) Special 2016, Pages: 157-163

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Effect of wildfire on soil-water characteristics of natural slope containing temperature sensitive silica-alumina polymorph minerals

Mohd Yuhyi Mohd Tadza and Anis Ayesha Noraini

Universiti Malaysia Pahang, Faculty of Civil Engineering & Earth Resources, 26300 Gambang, Kuantan, Malaysia

Address For Correspondence:
Mohd Yuhyi Mohd Tadza, Universiti Malaysia Pahang, Faculty of Civil Engineering & Earth Resources, 26300, Lebuhraya Tun Razak, Gambang, Kuantan, Malaysia.
E-mail: dryuhyi@ump.edu.my

ARTICLE INFO

Article history:
Received 19 August 2016
Accepted 10 December 2016
Published 31 December 2016

Keywords:
SWCC, post fire, suction, erosion, chilled-mirror hygrometer

ABSTRACT

Wildfires increased hillslopes erosion and surface runoff. The effect increased by several magnitudes when subjected to high intensity of precipitation during prolonged rainy seasons. The changes in geotechnical properties of soils affected by wildfire may jeopardize the stability of the slopes. In this study, soil specimens containing thermal sensitive nesosilicate polymorphs undergone wildfire and non-exposed to fire were collected and tested in order to understand the changes to the geotechnical properties and water retention behavior. Similarly, the changes to the slope were monitored up to a period of 270 days. The suction-water content soil water characteristic curves (SWCCs) were established for the soils using a chilled mirror dew-point hygrometer. In addition, the changes in the mineral compositions were also evaluated using X-ray diffraction analysis. Test results indicated that, the plasticity characteristics of the soils decreased after being burned. Concurrent to the decreased in the plasticity, the suction-water content established for soil exposed to wildfire was found to be slightly lower than that of unburned soils for suction lower than 1.5 MPa. Nesosilicates was found to be completely altered and affected by fire, whereas quartz minerals were found to be unaffected. Erosion occurred on-site was found to be attributed to reduction in the plasticity characteristics and changes to the overall mineral structure of the soil. Furthermore, the removal of vegetation as affected by fire reduced the slope surface cover and caused erosion of the slope to occur.

INTRODUCTION

Global temperature has increased 0.6°C in the past three decades, but it increased to 0.8°C in the past century (Hansen *et al*., 2006). Global temperature will warm up by 1.5°C to 4.5°C if the carbon dioxide concentration reaches the predicted level of 600 parts per million by the year 2050 (Masih, 2010; Solomon *et al*., 2009). As anthropogenic warming continues, the characteristics of droughts and heat waves will also be altered (Tangang *et al*., 2012). Furthermore, due to climate change, the effect of global warming has become more prominent. The Malaysian Meteorological Department recorded an increase in the average temperature to about 0.5°C to 1.3°C, when comparing the long term means obtained for 1961-1990 and 1998-2007. Based on these records, it is anticipated that the projected temperature increase in the next 30 years is between 1.0°C to 3.5°C.

Prolonged heat wave such as El Nino effect lead to a much drier forest and make fire ignition occur easier (Wotton and Flannigan, 1993). The relationship between meteorological conditions and fire occurrence is well established. Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Pinol *et al*., 1998). In Malaysia for instance, approximately 2,940 forest, bush fire outbreaks were recorded

To Cite This Article: Mohd Yuhyi Mohd Tadza and Anis Ayesha Noraini., Effect of wildfire on soil-water characteristics of natural slope containing temperature sensitive silica-alumina polymorph minerals. ***Aust. J. Basic & Appl. Sci.,*** *10(17): 157-163, 2016*

within 10 days during dry season in April 2016 (Bernama, 2016). This event brought about severe depletion of vegetation (i.e. slope natural cover). Vegetation and trees on slope induced soil suction and absorb excess water during rainfall (Rees and Ali, 2006; 2012). A study conducted by Rees and Ali (2012) noted that, the presence of vegetation increased slope stability by about 8%. Thus, in absence of vegetation, direct contact of precipitation on burned or dried slopes lead to an increased in hillslopes erosion and surface runoff. Moreover, the amount of precipitation is expected to be greater and longer during the Monsoon season between August and November. These two combination proves to be ideal yet devastating on the disintegration of slopes.

Wildfires has led to the increase in landscape's vulnerability to extreme flooding and soil erosion (Stoof *et al*., 2010). Fire is classified into three criteria according to its severity depending upon burned area affected (DeBano, 1999). During wildfires, maximum ground temperatures are typically in the range of 200°C to 300°C. In heavy fuels like slash, soil surface maximum temperatures are usually around 500°C to 700°C, but instantaneous temperatures in excess of 1500°C can also occur (Neary *et al*., 1999). According to Beyers *et al*. (2008), temperature in the forest floor can easily reach 600°C or higher during burning.

Although contradictory, the effect of fire on soil properties has been reported in the literature (see Stoof *et al*., 2010; Bento-Gonçalves *et al*., 2012). In essence, fire and associated soil heating can destroy soil structure, affecting the physical, chemical, biological and mineralogical soil properties in the surface horizons of a soil (Certini, 2005; DeBano, 1999; Solera *et al*., 2011). Fires are also known to alter soil properties that influence soil-water retention (Stoof *et al*., 2010). Typically, soils exposed to fire developed lower water retention characteristics and higher water repellency. Others reported that burned soils have an increase in the water content (Mallik *et al*. 1984), whereas Are *et al*. (2009) reported that water content of burned soil remained unchanged. The differences in the findings of these studies could be due to the severity, duration and temperature of the fire. The magnitude of change occurring during a fire depends heavily upon the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface, and the threshold temperatures at which the different soil properties change (Beyers *et al*., 2008). In addition, these differences could also attributed to the changes in the physico-chemical and mineralogical properties of the soils.

Most soil minerals are stable and unaffected at temperature below 100°C (Abu-Zreig, 2001). Alterations of the mineralogical characteristics would inevitably lead to a change in the water retention behavior. For instance, clay soils having different minerals and physico-chemical properties show different water retention behaviors when subjected to similar drying conditions (Tripathy *et al*., 2014a). Similarly, changes in clay mineral structure show non-plastic behavior at temperature beyond 400°C, indicating that water retention ability of the soils were completely deteriorated at higher temperatures due to changes in the mineralogical characteristics (Grim, 1968; Tan *et al*., 2004). Apparently, some soils contained temperature sensitive nesosilicate minerals. Nesosilicates are silica-alumina oxide having the chemical formula of Al_2SiO_5 (Anthony *et al*., 1997). The occurrence of nesosilicates in Malaysia was first reported by MacDonald (1968). Nesosilicates may exist in three different phases (i.e. different mineralogical structure) depending upon surrounding temperature and pressure (Althaus, 1967; Bohlen *et al*., 1991; Whitney, 2002) with mullite as the most stable form (Bradt, 2008). Thus, in the event of wildfire, the changes in the mineral structure of nesosilicates are expected to occur given that wildfire could have a temperature exceeding 400°C. It is anticipated that, these changes would resulted in increased soil erosion problems during heavy rainfall.

In general, soil surface above the groundwater table are often unsaturated (Fredlund and Rahardjo, 1993). Soil suction plays an important role in determining the soil behavior within this region. The behavior of unsaturated soil is strongly dependent on the physical, chemical and mineralogical properties (Fredlund and Rahardjo, 1993; Lu and Likos, 2004; Mitchell and Soga 2005). Determination of soil-water characteristic curve (SWCC) is prerequisite in the understanding of unsaturated soil behavior functions. Similarly, the SWCCs of soils exposed to fire are often established to determine the changes occurred to the soil engineering behaviors (Stoof *et al*., 2010). The suction-water content during wetting and drying are commonly established in the laboratory using axis-translation, osmotic and vapor equilibrium techniques (Fredlund and Rahardjo, 1993; Fleureau *et al*., 1993; Ng and Menzies, 2007; Delage *et al*., 2008; Tripathy *et al*., 2014a; Mohd Tadza *et al*., 2016b). In recent years, the development of chilled-mirror dew-point hygrometer has gained widespread acceptance as a fast and reliable method for establishing suction-water content SWCCs (ASTM D6836-02, 2003; Rorke *et al*., 2016; Mohd Yuhyi *et al*., 2016a). To date, the water retention characteristics of soil containing nesosilicate polymorphs and the effect of fire remains unexplored. Additionally, the changes in the geotechnical properties and water retention behavior of such soil has not been investigated and well understood. This paper aims to provide insight within this context. The work in this article consists of laboratory experiments that were conducted to study the effect of wildfire on the properties and the mineralogical changes of slope containing nesosilicate minerals.

Experimental Approach:

Sampling of soil samples were carried out at a site affected by wildfire. Burned and unburned soil sampling was obtained from natural slope at Jalan Gambang in Kuantan (N 3º 42' 45.124'', E 103º 7' 44.221''). The slope is located in the Eastern Belt where andalusite deposits can abundantly be found. According to Hutchison (1983), andalusite deposits in the area extend approximately 50 km radius from Gambang to Sungai Lembing. The slope considered in this study was 315 m in length and a portion of the slope (about 131 m) was affected by wildfire. Burned samples were obtained directly from the fire affected area, whereas unburned samples were collected on unaffected area about 1.8 m from the burned soils. Using a hand auger, disturbed soil samples were collected at burned site to a depth of about 20 cm below the ground surface. The samples were then crushed and sieved passing 425 μm before being placed in sealed bags prior to being tested in the laboratory. The burned site was then monitored and observed for any changes up to a period of 270 days.

The geotechnical properties namely, specific gravity, liquid and plastic limits burned and unburned soils were determined according to BS1377 standard laboratory procedures. Determination of the shrinkage limit and organic matter of the soils were carried out following ASTM D4943–08 and ASTM D4829-11, respectively. An X-ray diffraction (XRD) device was employed to investigate the changes in the mineralogical compositions of the soil samples. A Rigaku Miniflex II was employed for this propose. Additionally, the changes in the specific surface area of the soil samples were determined using an Accelerated Surface Analyzer ASAP 2020 from Micromeritics.

In establishing the suction-water content relationships, a chilled-mirror dew-point hygrometer was used. A Decagon WP4C chilled-mirror dew-point hygrometer was used for this purpose. Soil-water mixtures were initially prepared by mixing soil powder specimens with deionized water at increments of about 2%. The soil-water mixtures were then allowed to cure for 7 days before being tested. All suction measurements in this study were carried out at 25ºC using the "precise mode". During measurements, the specimen holder was filled with approximately 5 g of soil-water mixtures, less than half of the volume (6 cm3). This step was taken to minimize contamination to the testing chamber. Initially, all specimens were thermally pre-conditioned to meet the device inner block's temperature before being tested (Tripathy and Rees, 2013; Mohd Yuhyi *et al*., 2016b).

RESULTS AND DISCUSSION

The changes on the wildfire affected site in this study is presented in Figure 1. Upon inspection of the site, it was observed that the slope was completely charred. The fire had destroyed most of the vegetation on the slope. The surface of the slope was grey to black in color and covered with ash derived from burning of the vegetation. Samples excavated from the burned area revealed that the depth of charred soil was extended to about 7 cm from the surface. The change in the color along with depth was noticeable (i.e. greyish black to brown). It could be attributed to charred soil or penetration of ash into the soil mass (Stoof *et al*., 2010).

Fig. 1: Changes on the slope affected by wildfire in this study, a) after wildfire (i.e. 0 days), b) after 32 days, c) after 270 days

Another image of the slope at the same location was taken after 32 days (see Fig. 1b). Heavy precipitation occurred the night before the image was captured. Thinning of the slope was observed and the top part of the slope (i.e. blackened layer) was washed out. The eroded material was found to be deposited at the toe of the slope. The amount of eroded material was not measured in this study, thus the magnitude of erosion was unknown. Surprisingly, after 32 days, some sign of growth vegetation was observed. Figure 1c shows the image of the same location after a period of 270 days. Increased in number of plant growth were observed in the slope. Interestingly, rampant growth of vegetation was more prominent on the toe of the slope (i.e. deposition of eroded material). In response to the increase and availability of organic carbon, lusher growth of vegetation was observed. Similar observation was made on the application of charred material on growth of plants (Atkinson *et al*., 2010)

The geotechnical and mineralogical properties of the burned and unburned soils used in this study are presented in Table 1. Some differences were noted between both unburned and burned soils. Decrease in the specific gravity, liquid limit, surface area and free swell parameters were observed. The test results were found to be in good agreement with the test results reported in the literature (Abu-Zreig, 2001; Tan *et al*. 2004; Young-

Suk Song, 2007). In contrast, the fire increased the plastic limit, shrinkage limit and organic content of the burned soil. Both increased in the plastic and shrinkage limit was noted may be due to infiltration of ash in the soil after being burned (Stoof *et al*., 2010). Carbon or ash content due to burned material may absorbed some water thus, lead to the increase in the plastic and shrinkage limit of the soil (Malusis *et al*., 2009; Stoof *et al*., 2010).

Table 1: Geotechnical and mineralogical properties of unburned and burned soils in this study.

Geotechnical properties	Unburned	Burned
Specific gravity, *Gs*	2.65	2.58
Liquid limit, *wl* (%)	57	55
Plastic limit, *wp* (%)	30	37
Shrinkage limit, *ws* (%)	22	24
Surface area, *S* (m^2/g)	20.6	11.9
Organic content (%)	0.36	0.51
Free swell (%)	5.4	4.6
Color	Brown	Greyish black
Mineralogical properties (%)		
Kyanite	-	78.3
Andalusite	78.6	-
Quartz	21.4	21.7

The mineral composition of both soil were found to be comparable although different. Comparable amounts of nesosilicates and other minerals were observed in both burned and unburned soil samples. Remarkably, comparison of XRD test results showed that, initially unburned soil samples predominantly consists of andalusite. However, mineralogical structure after exposed to wildfire was completely altered. In this case, rather than andalusite, the burned soil sample consists mainly of kyanite. Due to temperature sensitive in nature of nesosilicates, it is expected that the change in the mineralogical composition would occur. Generally, kyanite is stable in low temperature and low pressure environment. Increasing temperature would lead to the transformation of kyanite to andalusite and further change to silimanite (Whitney, 2002). At temperature exceeding 1100°C kyanite decomposed into mullite (Speyer, 1993). The findings of this study was found to be similar to that of Whitney (2002), where formation of andalusite to kyanite occurred in Turkish geological formation. Post wildfire revealed that all andalusite minerals in unburned soil sample were converted to kyanite minerals. Interestingly, it was noted that the fire did not affect the nesosilicates into its most stable form (i.e. mullite). Referring to Table 1, traces of quartz minerals were also present in both soils. In this study, fire was found to have no effect on this type of minerals.

Figure 2 shows the water retention curves for both soils. Good agreements were noted between water retention behavior of the soil for burned and unburned conditions at measured suction of 2 to 10 MPa. At suction lower than 1.5 MPa, however it was noted that the water contents of the burned soil was lower than the unburned counterpart. At higher suctions, the surface area plays a vital role in determining the water retention behavior of soils (Santamarina *et al*., 2002; Tripathy *et al*., 2014a). On the other hand, at lower suctions the physico-chemical forces are more dominant in governing the water retention behavior of soils (Tripathy *et al*., 2004; Tripathy *et al*., 2014b). Concurrent with the decrease in surface area, the swelling potential, liquid limit and water retention of burned soil was found to be lower than the unburned soil (see Table 1 and Fig. 2). The differences in water retention behaviors of burned and unburned soil samples could also attributed to the change in the mineralogical characteristics of the soil.

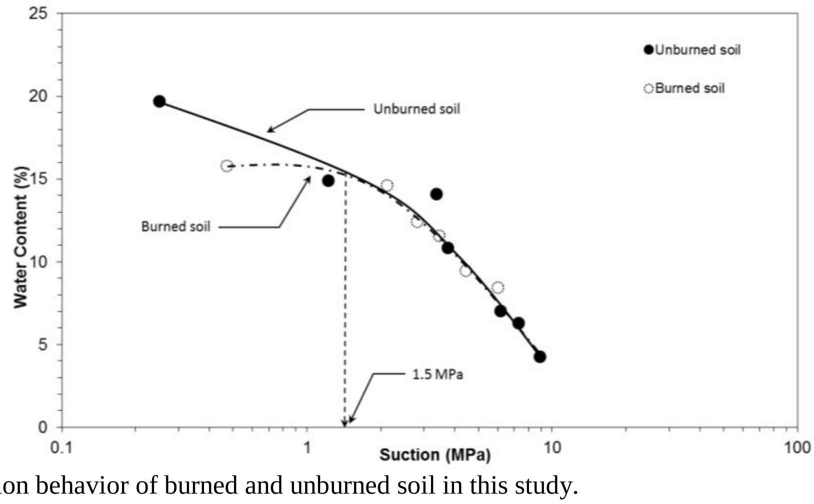

Fig. 2: Water retention behavior of burned and unburned soil in this study.

Based on the water retention curves, clearly that at low suction (i.e. high water content), the ability of the burned soil to absorbed water was limited. From engineering perspectives, a decrease in the plasticity characteristics and water retention behavior would lead to reduction in the shear strength (i.e. loss of cohesion) (Yilmaz, 2011; McCartney *et al*., 2014). Shear strength is a crucial parameter which governs the ability of soil to remain stable under shear stress. During prolonged or heavy rainfall, the critical shear stress increased with the increase in water flow on the burned slope and promotes erosion. Coupled with the absence of vegetation, erosion of the slope became more severe, explaining the reason for eroded material deposition at the slope’s toe (see Fig. 1b). Changes to the geotechnical properties due to fire should be taken into consideration for the design of the slope in order to maintain the long-term stability and integrity of the slope. The wildfire temperature was not measured and could not be precisely determined in this study. It was speculated that the temperature of the fire was within 200 to 800°C given that kyanite and andalusite are generally formed within this range of temperatures Hutchison (1971). Similarly, this range of temperature would not affect the mineralogical changes of quartz minerals (Liu *et al*., 2016).

Conclusion:

The effect of wildfire on slope containing sensitive nesosilicates were evaluated. Based on the findings of this study, the following conclusions were drawn.

i. Wildfire affected the geotechnical properties of the soil. Basically, wildfire reduced the specific gravity, liquid limit, surface area and free swell parameters in this study. However increased in other parameters such as the plastic limit, shrinkage limit and organic content of the soil studied were noted. Ash content slightly increase the plasticity and shrinkage limits of the burned soil.

ii. A complete change in the mineralogical characteristics of nesosilicates was observed. Andalusite minerals in this study were converted to Kyanite after exposed to wildfire. Quartz minerals on the other hand, was found to be unaffected by the fire.

iii. Similar water retention curves were obtained for both soils at higher suctions, however at suctions lower than 1.5 MPa, a much lower water retention characteristic was observed for burned soil. Concurrent with the decrease in surface area and the change in the mineral compositions, the water contents of burned soil was found to be limited. The reduction in the plasticity characteristics and water retention behavior may led to decrease in the shear strength due to loss of cohesion. This reduction resulted in soil erosion of the slope.

iv. Slope erosion was observed and top soil and ash were washed along with runoff during heavy rainfall. The eroded material deposited at the slope’s toe. Lack of vegetation to induced suction in soil contributed to the erosion of the slope. First sight of vegetation was observed after a period of 32 days. Increased in the amount of ash or carbon content in the eroded material led to a much lusher growth of vegetation after a period of 270 days.

v. The changes to the overall geotechnical properties should be taken into consideration in the design of fire affected slopes to ensure long-term stability of the slopes.

vi. The wildfire in this study could have occurred at a temperature of about 200 to 800°C, given that kyanite and andalusite are commonly formed within this range of temperatures.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Universiti Malaysia Pahang for providing financial support under research grant RDU 130384 and GRS 130582. The authors would also like to thank the Malaysian Nuclear Agency for providing the chilled-mirror dew-point potentiometer used in this study.

REFERENCES

Abu-Zreig, M.M., N.M. Al-Akhras and M.F. Attom, 2001. Influence of heat treatment on the behavior of clayey soils. Applied Clay Science, 20(3): 129-135.

Althaus, E., 1967. The triple point andalusite-sillimanite-kyanite. An experimental and petrologic study.

Anthony, J.W., K.W. Blahd, M.C. Nicholas and R.A. Bideaux, 1997. Handbook of mineralogical. Mineral Data Publishing.

Are, K.S., G.A. Oluwatosin, O.D. Adeyolanu, A.O. Oke, 2009. Slash and burn effect on soil quality of an Alfisol: soil physical properties. Soil and Tillage Research, 103(1): 4-10.

ASTM, 2008. D4943-08. Standard test method for shrinkage factors of soils by the wax method.

ASTM, 2008. D6836-02. Standard test methods for determination of the soil water characteristic curve for desorption using a hanging column, pressure extractor, chilled mirror hygrometer, and/or centrifuge.

ASTM, 2010. D4829-11. Standard test method for expansion index of soils.

Atkinson, C.J., J.D. Fitzgerald and N.A. Hipps, 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review Plant Soil, 337(1): 1-18.

Bento-Goncalves, A., A. Vieira, X. Ubeda and D. Martin, 2012. Fire and soils: Key concepts and recent advances. Geoderma, 191: 3-13.

Bernama, 2016. 2,940 Forest, bush fire outbreaks recorded in 10 days.

Beyers, J.L., J.K. Brown, M.D. Busse, L.F. DeBano, W.J. Elliot, P.F. Ffolliott, G.R. Jacoby, J.D. Knoepp, J.D. Landsberg, D.G. Neary, J.R. Reardon, J.N. Rinne, P.R. Robichaud, K.C. Ryan, A.R. Tiedemann and M.J. Zwolinski, 2008. Wildland fire in ecosystem: effects of fire on soils and water. Gen. Tech. Rep. RMRS- GTR, 42(4): 250.

Bohlen, S.R., A. Montana, D.M. Kerrick, 1991. Precise determination of the equilibria kyanite = sillimanite and kyanite = andalusite and a revised triple point for Al2SiO5 polymorph. American Mineralogist, 76: 677-684.

Bradt, R.C., 2008. The Sillimanite Minerals: Andalusite, Kyanite, and Sillimanite. In Ceramic and Glass Materials, Shackelford, J.F. and R.H. Doremus: Springer, pp: 41-48.

BS 1377, 2012. Methods of tests for soils for civil engineering purposes.

Certini, G., 2005. Effects of fire on properties of forest soils: a review. Oecology, 143(1): 1-10.

DeBano, L.F., 1999. The role of fire and soil heating on water repellency in wildland environments: a review. Journal of Hydrology, 231: 195-206.

Delage, P., E. Romero and A. Tarantino, 2008. Recent developments in the techniques of controlling and measuring suction in unsaturated soils. In Saturated Soils: Advances in Geo-Engineering, Taylor and Francis Group, London: 33-52.

Fleureau, J.M., S. Kheirbek-Saoud, R. Soemitro and S. Taibi, 1993. Behavior of clayey soils on drying-wetting paths. Can. Geotech. J, 30(2): 287-296.

Fredlund, D.G. and H. Rahardjo, 1993. Soil mechanics for unsaturated soils. John Wiley & Sons.

Grim, R.E., 1968. Clay mineralogy. McGraw-Hill.

Hansen, J., M. Sato, R. Ruedy, K. Lo, D.W. Lea and M. Medina-Elizade, 2006. Global temperature change. Proceedings of the National Academy of Sciences, 103(39): 14288-14293.

Hutchison, C.S., 1971. Meditations on metamorphism. Bulletin of the Geological Society of Malaysia, 4:1-13.

Hutchison, C.S., 1983. Multiple Mesozoic Sn-W-Sb granitoids of southeast Asia. In Circum-Pacific Plutonic Terranes, Roddick, J.A.: Geological Society of America Memoirs, pp: 35-60.

Larsen, I.J., L.H. MacDonald, E. Brown, D. Rough, M.J. Welsh, J.H. Pietraszek and K. Schaffrath, 2009. Causes of post-fire runoff and erosion: water repellency, cover, or soil sealing?. Soil Science Society of America Journal, 73(4): 1393-1407.

Liu, X., C. Zhang, S. Yuan, S. Fityus, S.W. Sloan and O. Buzzi, 2016. Effect of High Temperature on Mineralogy, Microstructure, Shear Stiffness and Tensile Strength of Two Australian Mudstones. Rock Mechanics and Rock Engineering, 49(9): 3513-3524.

Lu, N. and W.J. Likos, 2004. Unsaturated soil mechanics. Wiley.

MacDonald, S., 1968. Geology and Mineral resources of North Kelantan and North Terengganu. Geological Survey West Malaysia. Mem. Geol. Surv. Malaysia (Malaya), 10: 202.

Mallik, A.U., C.H. Gimingham and A.A. Rahman, 1984. Ecological effects of heather burning. I. Water infiltration, moisture retention and porosity of the surface soil. Journal of Ecology, 72: 767-776.

Malusis, M.A., E.J. Barben, J.C. Evans, 2009. Hydraulic conductivity and compressibility of soil-bentonite backfill amended with activated carbon. Journal of Geotechnical and Geoenvironmental Engineering, 135(5): 664-672.

Masih, J., 2010. Causes and consequences of global climate change. Archives of Applied Science Research 2(2): 100-108.

McCartney, J. S., C.J.R. Coccia, N.A. Alsherif, M.A. Stewart, T. Baser, T. Traore, & J.C. Goode III, 2014. Unsaturated Soil Mechanics in Geothermal Energy Applications. In Unsaturated Soils: Research & Applications, Khalili, N., A. Russell, A. Khoshghalb: CRC Press, pp: 835-842.

Mitchell, J.K. and K. Soga, 2005. Fundamentals of soil behaviors. John Wiley and Sons Inc.

Mohd Tadza, M.Y., M.F. Farida, M.A. Mohd Tadza, J. Ismail, N. Mahazam and S.M. Mohd Azmi, 2016b. Intrusion of polyethylene glycol during osmotic tests: identifying cellulose acetate degrading microbes. Jurnal Teknologi (Sciences & Engineering), 72: 16.

Mohd Tadza, M.Y., N.S. Mohd Azmi, R. Mustapha, N.D. Desa and K. Samuding, 2016a. Malaysian alternative to international reference bentonite buffer in underground nuclear waste repository. First Annual WiN Malaysia Conference 2016. AIP Publishing.

Neary, D.G., C.C. Klopatek, L.F. DeBano and P.F. Ffolliott, 1999. Fire effects on belowground sustainability: a review and synthesis. Forest ecology and management, 122(1): 51-71.

Ng, C.W.W. and B. Menzies, 2007. Advanced Unsaturated Soil Mechanics and Engineering. Taylor & Francis.

Pinol, J., J. Terradas and F. Lloret, 1998. Climate warming, wildfire hazard and wildfire occurrence in coastal eastern Spain. Climatic change, 38(3): 345-357.

Rees, S.W. and N. Ali, 2006. Seasonal water uptake near trees: a numerical and experimental study. Geomechanics and Geoengineering: An International Journal, 1(2): 129-138.

Rees, S.W. and N. Ali, 2012. Tree induced suction and slope stability. Geomechanics and Geoengineering, 7(2): 103-113.

Rorke, L., S. Tripathy, L. Otter, C.R.I. Clayton and W. Powrie, 2015. Use of a chilled-mirror dew-point potentiometer to determine suction in a railway formation material. In Proceedings of the First Southern African Geotechnical Conference, edited by S.W. Jacobsz CRC Press, pp: 229.

Santamarina, J.C., K.A. Klein, Y.H. Wang and E. Prencke, 2002. Specific surface: determination and relevance. Canadian Geotechnical Journal, 39(1): 233-241.

Solera J.M., A. Cerda, V. Arcenegui, A. Jordan and L.M. Zavala, 2011. Fire effects on soil aggregation: a review, 109(1): 44-60.

Solomon, S., G.K. Plattner, R. Knutti and P. Friedlingstein, 2009. Irreversible climate change due to carbon dioxide emissions. In Proceedings of the National Academy of Science, pnas-0812721106.

Song, Y.S. and B.G. Chae, 2007. Change for engineering properties of top soils in wildfire area. The Journal of Engineering Geology, 17(2): 225-233.

Speyer, R., 1993. Thermal analysis of materials. CRC Press.

Stoof, C.R., J.G. Wesseling and C.J. Ritsema, 2010. Effects of fire and ash on soil water retention. Geoderma, 159(3): 276-285.

Tan, O., L. Yilmaz, A.S. Zaimoglu, 2004. Variation of some engineering properties of clays with heat treatment. Materials Letters, 58(7): 1176-1179.

Tangang, F.T., L. Juneng, E. Salimun, K.M. Sei, L.J. Le and H. Muhamad, 2012. Climate change and variability over malaysia: gaps in science and research information. Sains Malaysiana, 41(11): 1355-1366.

Tripathy S., A. Sridharan and T. Schanz, 2004. Swelling pressures of compacted bentonites from diffuse double layer theory. Canadian Geotechnical Journal, 41(3): 437-450.

Tripathy S., M.Y. Mohd Tadza and H.R. Thomas, 2014a. Soil-water characteristics curves of clays. Canadian Geotechnical Journal, 51(8): 869-883.

Tripathy, S. and S. Rees, 2013. Suction of some polyethylene glycols commonly used for unsaturated soil testing. ASTM Geotechnical Testing Journal, 36(5): 768-780.

Tripathy, S., R. Bag and H.R. Thomas, 2014b. Effect of Stern-layer on the compressibility behaviour of bentonites. Acta Geotechnica, 9(6): 1097-1109.

Vermiere, L.T., D.B. Wester, R.B. Mitchell and S.D. Fuhlendorf, 2005. Fire and grazing effects on wind erosion, soil water content, and soil temperature. Journal of Environmental Quality, 34(5): 1559-1565.

Whitney, D.L., 2002. Coexisting andalusite, kyanite and sillimanite: Sequential formation of three Al2SiO5 polymorphs during progressive metamorphism near the triple point, Sivrihisar, Turkey. American Mineralogist, 87(4): 405-416.

Wotton, B.M. and M.D. Flannigan, 1993. Length of the fire season in a changing climate. Forestry Chronicle, 69:187-192.

Yilmaz, G., 2011. The effects of temperature on the characteristics of kaolinite and bentonite. Scientific Research and Essays, 6(9): 1928-1939.