Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 187–197

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full length article

Effect of interfacial properties on mechanical stability of ash deposit

A. Ontiveros-Ortega [a,b,*], J.A. Moleon [a], I. Plaza [a], C. Guillén [c]

[a] Department of Physics, Campus Universitario de las Lagunillas s/n, Edificio A-3, University of Jaén, Jaén, 23071, Spain
[b] Instituto Andaluz de Geofísica, University of Granada, Granada, 18071, Spain
[c] Department of Geography, Campus Universitario de Guajara s/n, University of La Laguna, Islas Canarias, 38071, Spain

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form
14 October 2015
Accepted 26 October 2015
Available online 27 January 2016

Keywords:
Zeta potential
Surface free energy
Volcanic ash
Deposits stability
El Hierro Island

ABSTRACT

The paper presents a study on the cohesion of volcanic ash particles using surface free energy determination and zeta potential analyses. This is a subject of great interest in physical volcanology, as many researches on volcanic particle aggregation are frequently reported. In this case, special attention is paid to the role of structural or hydration forces between hydrophilic surfaces, which are a consequence of the electron-donor/electron-acceptor character of the interface. From this point of view, the results are potentially interesting as they could give valuable insights into this process. The results are presented in terms of the total energy of interaction between dispersed particles, computed from the extended DLVO theory. Contributions to the total free energy of interaction were determined from the zeta potential and surface free energy of ash, measured under different experimental conditions. Two samples of basaltic volcanic ash (black and white) with silica contents of 44% and 63% respectively are studied. The surface free energy and zeta potential were analysed for ashes immersed in different electrolytes (NaCl, $CaCl_2$, $FeCl_3$). The presence of electrolytes changes the surface properties of the solid materials. The analysis of total interaction energy between the ash particles in aqueous medium shows that soil cohesion strongly depends on ash surface properties, chemical nature, the adsorbed cation on the surface, and pH value.

1. Introduction

Volcanic soils are encountered in many countries around the world and dominate the surface geology in several areas of high population density. Furthermore, many of the areas where volcanic soils are predominant are within tropical regions with high annual rainfalls and frequently intense precipitation. Volcanic soils support near-vertical slopes, which are often totally denuded of vegetation, are susceptible to sudden and catastrophic failure (Bommer et al., 2002). The El Hierro Island is one of the regions where earthquake-induced landslides constitute significant natural hazards. Mitigation of landslide hazards in regions such as Canary Island first requires a thorough understanding of the behaviour of these volcanic soils under static and dynamic conditions.

Gonzalez de Vallejo et al. (1981) presented a study of a volcanic soil located in Tenerife, Canary Island, Spain. The soil shows a general tendency to form aggregations of clay particles, usually showing different fabrics and levels of cementation. The cohesion of ash deposits depends on several factors. Rheological properties in aqueous media are influenced by the interactions between particles. The control of flocculation phenomena, adsorption, wetting and rheological properties of dispersion depends on the particle interactions (Plaza et al., 1998; Bailey et al., 2009; Cockell et al., 2010; Gimmi and Kosakowski, 2011; Baumgarten et al., 2012, 2013; Kadar et al., 2014; Ontiveros-Ortega et al., 2014). Much of the scientific and technological interest in clay minerals derives from their interfacial interactions with colloidal particles (clays and other minerals) in the presence of a liquid, most often water. Andosols are highly sensitive to any mechanical disturbance, but they have the potential to recover their structure after a certain rest time (Rao, 1995). However, the mechanism of thixotropy in these soils on the particle-to-particle scale is still not well understood. The investigation of thixotropy in volcanic ash soils is relevant to greater comprehension of mechanical behaviour at various scales as induced by trampling or remoulding, for example, for understanding dynamic processes such as landslides (Li et al., 1997; Baumgarten et al., 2013).

Surface thermodynamic theory can describe the interactions between condensed-phase materials across an interface and therefore provides a basis for a natural and quantitative definition of cohesion of volcanic ash deposits, and for total interaction energy in the form of the free energy of interfacial interaction between particles in an aqueous environment (van Oss and Good, 1989; Duran et al., 1998). Such a definition can reveal which properties

---

[*] Corresponding author. Tel.: +34 953 212830.
E-mail address: aontiver@ujaen.es (A. Ontiveros-Ortega).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2015.10.008

of the materials and of the liquid medium are responsible for the interfacial behaviour and therefore soil cohesion.

This work deals with the total energy of interactions between colloidal ash particles in different experimental conditions. Special attention is paid to the role of interfacial interactions, not only electrostatic and van der Waals but also structural or hydration forces between hydrophilic surfaces, which are a consequence of the electron-donor/electron-acceptor character of the interface (van Oss, 1994). A similar approach has been used to explain bacteria adhesion on volcanic glass (Ontiveros-Ortega et al., 2014), zinc sulfide on silicon (Duran et al., 1998), or calcium carbonate on glass (Ontiveros et al., 1996a). We also focus our interest on the fact that aggregation processes depend strongly on pH value and ionic strength of the aqueous medium, similar to the effect that various cations have on the cohesion of deposits.

The tectonic processes that give rise to the volcanism responsible for the formation of these deposits tend to occur in areas of high seismic hazards. The El Hierro Island is one region where volcanic soils are abundant and earthquake-induced landslides constitute significant natural hazards (Masson et al., 2006). The submarine eruption of “El Mar de las Calmas” at the El Hierro Island (Perez et al., 2015) developed on a submarine slope about 2 km from the southern tip of the island, between October 2011 and March 2012. This eruption revealed the need to characterise in detail the most recent eruptive history of the island, in order to know and minimise the effects of probable future eruptive episodes.

In the southwestern part of the Canary Islands with the area of 268.7 km^2 (Instituto Canario de Estadística), volcanism emerged only 1.2 million years ago (Guillou et al., 1996) on the El Hierro Island. It has the smallest surface area and the youngest geological age of all the Canary Islands. Its geological history is characterised by a succession of three volcanic cycles linked with the development of several volcanic edifices (Guillou et al., 1996; Balcells and Gomez, 1997a, b, c, d). The initial volcanic activity is associated with formation of the Tiñor Edifice in the northeast of the island, with the age of 1.12–0.88 million years. The collapse of the north side of this edifice at 888 thousand years ago was subsequently silted up by the lava edifice “El golfo-Las playas” (545–176 thousand years), and then affected by large landslides over 130–80 thousand years (Longpre et al., 2011).

Around 158 thousand years ago, volcanism of the northwest, northeast and south-southeast rifts started (Guillou et al., 1996), which has continued without major interruption (Pérez Torrado et al., 2011) to the present day. Volcanic activity of the rifts largely coincides with the intermediate series (Coello, 1971; Pellicer, 1977), undifferentiated series and cliff- and platform-forming formations (Carracedo et al., 2001). El Hierro has a total of 179 monogenetic eruptive centres, 78 of which are developed in the northeast rift, 62 in the west, and 39 in the south (Becerril et al., 2013).

The Holocene period has only five datings, and some of them are unassociated with accurate emission centres: (1) Emission centre without precise location, in the southwest rift, dated at 8.3 thousand years (Pérez Torrado et al., 2011); (2) Tanganasoga Volcano in the southwest rift, dated at 6.74 thousand years (Pellicer, 1977); (3) Humilladero Mountain in the southwest rift, dated at 5.1 thousand years (Pérez Torrado et al., 2011); (4) Emission centre without precise location in the west-southwest rift, dated at 3.5 thousand years (Pérez Torrado et al., 2011); and (5) Chamuscada Mountain in the northeast rift, dated at 2.5 thousand years (Carracedo et al., 2001).

Following its conquest by the Spanish, there were references to possible volcanic activities on the island. Controversy surrounding these references can be found in Bravo (1968), Hernández Pacheco (1982), and Romero (1991). Nonetheless, the submarine eruption of Mar de las Calmas is the first eruptive event observed on the island in the last 500 years.

Most volcanism of rifts corresponds to mafic eruptions of basaltic nature, characterised by the construction of one or more volcanic edifices. These edifices are constituted by slag, lapilli, and abundant emission of lava flows. Eruptive mechanisms involved are mainly of Strombolian, but also have been described as having a phreatomagmatic character.

2. Materials

2.1. Chemical

All reagents and chemicals used were of analytical grade (NaCl, $CaCl_2$ and $FeCl_3$ provided by Sigma–Aldrich Co., USA; Diiodomethane and formamide by Merck KGaA. LLC, Germany). Water for surface free energy determination was twice-distilled, and Milli-Q reagent-grade water was used for electrophoretic measurements. Solution pH value was adjusted by adding a reagent-grade solution of either NaOH or HCl both provided also by Merck.

2.2. Random sampling

Two samples of cinder materials with very different features were collected (see Fig. 1). The first was taken around Malpaso Peak (1502 m) at 1046 m altitude, the coordinates of 27 R 791479/3070.212. In this place, there is a level of very fine loose ash, greyish (white ash, white triangle in Fig. 1), finely laminated and a general power of ~50 cm, which is covered at the top by a black lapilli layer. This cineritic layer has been previously described by Pellicer (1977) and Balcells and Gomez (1997b). They stated that these are the only pyroclastic deposits of composition salic on the El Hierro Island. These deposits may correspond to an episode of marked explosive features, which are believed to be prior to the formation of Tanganasoga Volcano. However, Pellicer (1979) associated them to a volcanic event after the formation of this volcanic edifice.

The second sample (black ash, black triangle in Fig. 1) was collected in a reservoir of basaltic pyroclastic of dispersal (coordinates of 27 R 786848/3068.855, altitude of 1023 m). The sample was taken from a cineritic level of black colour, fresh appearance, and very little consolidation. Balcells and Gomez (1997b) associated the presence of this very fine-grained level with pulses or phreatomagmatic phases linked to purely magmatic monogenic eruptions around the northwest ridge summits of the island.

3. Methods

3.1. Scanning electron microscope images of ash

Ash morphological aspect of soil structure is properly examined by scanning electron microscope (SEM). We used a scanning microscope with acceleration voltage of 25 kV (S-510; Hitachi Ltd., Tokyo, Japan) equipped with an energy-dispersive X-ray detector (EDAX; Rontec GmbH, Berlin, Germany). Fine ash was mounted on the sample holder with colloidal silver and metallised with gold deposited in two orientations (20°–30°). Conventional SEM images at low (3200), medium (11,200) and high (46,000) magnifications were obtained.

3.2. X-ray fluorescence

A wavelength dispersive X-ray fluorescence spectrometer (WDXRF) S4 explorer model pioneer from Bruker is used here. The spectrometer analyses elements from carbon to uranium in a wide