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Investigating the effects of micro-texture and geo-mechanical properties on the abrasiveness of volcanic rocks

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ABSTRACT

The abrasiveness of rocks is a fundamental rock property that affects sawing and cutting performance, wear of Tunnel Boring Machine (TBM) heads. The CERCHAR Abrasiveness Index (CAI) test is a commonly used procedure to define rock abrasivity. This paper investigates the relationship between quantitative mineralogical and petrographic data and CAI values for some selected volcanic rocks. In addition, the research examines the relationship between physical (e.g., effective porosity and P-wave velocities) and mechanical (e.g., uniaxial compressive strength (UCS), Brazilian Tensile Strength (BTS), Young's Modulus (E)) properties including brittleness values and CAI values.

Quantitative mineralogical and petrographic analyses reveal the variations in micro-textural properties as defined by different groundmass-phenocryst ratios. Analyses also suggest that the dimensions of opaque minerals and plagioclase feldspar apparently have individual effects on CAI values. Additionally, the combined effects of grain size and primary types of constituent minerals have a significant on CAI values. Additionally, results of physical and mechanical tests indicate that as P-wave velocities increase, CAI values increase. The increasing values of UCS, BTS and E cause CAI values to increase significantly. However, only one of three brittleness values was found to have a considerable relationship with CAI values.

This research demonstrates the importance of evaluating the micro-textural variations and the combined effects of micro-texture, physical properties and mechanical properties on the CAI values of volcanic rocks.

1. Introduction

It is widely known that micro-structural, mineralogical and petrographic properties of rocks determine the behavior of a rock under applied stress. The effects of micro-textural properties on the physical and mechanical properties of rocks have been investigated from different perspectives (Tapponnier and Brace, 1976; Ulusay et al., 1994; Přikryl, 2001, 2006; Tamrakar et al., 2007; Zorlu et al., 2008; Yeşiloğlu-Gültekin et al., 2013; Tandon and Gupta, 2013; Baud et al., 2014; Ündül, 2016). Among the many physical and mechanical properties of rocks, the abrasiveness of rocks is of particular interest based on its relationship to various types of excavating (e.g., tunneling, mining). This is due to the direct effect of abrasiveness on cutter heads, wear of TBM tunneling equipment, and excavation performance including delays, costs (Suana and Peters, 1982; Kahraman, 2002; Plinninger et al., 2003; Gong and Zhao, 2007; Yağız, 2009; Köhler et al., 2011; Tümaç, 2015; Tripathy et al., 2015; Moradizadeh et al., 2016).

The CERCHAR Abrasiveness Index (CAI) test (recommended by the French CERCHAR Institute, 1986) is one of the most commonly used laboratory methods to assess hard-rock abrasiveness because it is a simple and fast test procedure (Plinninger et al., 2003; Ko et al., 2016). To predict CAI values, researchers have utilized petrographic studies. Suana and Peters (1982), Atkinson et al. (1986) and Al-Ameen and Waller (1994) emphasized the importance of equivalent quartz content (i.e. a theoretical abrasivity meaning the entire mineral content referring to the abrasiveness or hardness of quartz Thuro, 1997), grain shape, grain size, hardness of mineral constituents and matrix properties in determining the abrasiveness of rocks. In addition to the petrographic factors, Plinninger et al. (2003) suggested that the combined assessment of Young's modulus and equivalent quartz content of a rock sample was best suited to interpret CAI values. Similarly, Ko et al. (2016) investigated the relationship between CAI, petrographic features and geo-mechanical properties on some metamorphic and igneous rocks utilizing single and multiple regression analyses. The authors found that one parameter alone is not suitable to predict the value of CAI. However, multiple regression analyses including multiple parameters such as UCS, brittleness and quartz content can be correlated with CAI values for igneous and metamorphic rocks. Moradizadeh et al.

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(2016) concluded that mineralogical factors in addition to strength affect the level of abrasion in sandstones, but in igneous and metamorphic rocks, there is no relationship between the strength and CAI; only mineralogy influenced abrasiveness. Furthermore, AbuBakar et al. (2016) investigated the effect of water content on the abrasiveness of rocks. The authors showed that the majority of CAI values obtained from saturated samples are lower than CAI values obtained from dry samples by a factor of 0.8. In addition to laboratory experiments, some soft computing techniques were developed to predict the abrasiveness of rocks given input of simple geo-mechanical parameters (Yağız et al., 2009; Yagiz and Gökçeoğlu, 2010; Kahraman et al., 2010; Tripathy et al., 2015).

Plinninger et al. (2003) and Rostami et al. (2014) highlighted some discrepancies in the results of CERCHAR tests regarding testing conditions, the condition of the rock surface and the effects of micro-texture. In addition, Tandon and Gupta (2013), Coggan et al. (2013), and Ündül et al. (2015) displayed the importance of quantitative micro-textural properties with respect to variations of physico-mechanical properties of rocks. Investigations focusing on the quantitative micro-textural parameters that influence CAI values of volcanic rocks are still limited in the literature. Thus, this study aims to investigate the influencing factors of CAI values of volcanic rocks that have different micro-textural properties. This study utilizes quantitative micro-textural parameters, physical properties, rock strength and deformation characteristics. Brittleness, which is defined as the failure of rock at or slightly above its yield stress (Hetenyi, 1966), was also considered. The most commonly used equations in predicting brittleness values considering UCS and Brazilian tensile strength were used during interpretations.

2. Sample description and methodology

Volcanic rock samples with different micro-textural properties were investigated in this study. Volcanic rocks in the sampling area (Çanakkale region NW of Turkey) are named the Hisarlıdağ volcanics and generally occur as lava flows, small dykes and sills, or volcaniclastic rocks interlayered with sedimentary strata (Akartuna, 1950; Temel and Çiftçi, 2002; Koral et al., 2009). Block samples (minimum size of 40 cm × 40 cm × 40 cm) were collected from Miocene lava flows of the Hisarlıdağ volcanics. The samples were carefully selected to exclude signs of weathering and macroscopic heterogeneity (e.g., veins, fractures, etc.) in order to avoid their negative effects on abrasiveness and other physico-mechanical properties. The block samples were collected from fresh and/or slightly weathered exposures, as described by ANON (1995). Sampling locations and general characteristics of samples are provided in Table 1. A total of 23 cores were over-cored from block samples and were extracted perpendicular to the lava flow direction for use in UCS and CERCHAR tests. The samples for each UCS and CERCHAR test were obtained from the cores shown in Fig. 1. The BTS samples were derived from areas in the sample blocks adjacent to core locations.

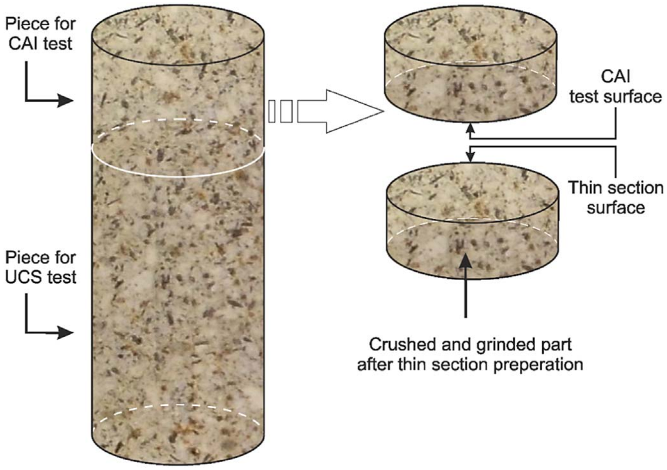

Fig. 1. Schematic view of the distribution of sampling sections in a core. The piece used for CAI testing was saw cut; one saw-cut surface was used for CERCHAR tests, and the opposing side was used for thin-section preparation. The remaining sample after thin section preparation was crushed and ground (Not to scale).

In general, the sampled volcanic rocks were macroscopically isotropic with a porphyritic texture lacking mineral lineation and mineral orientation. The samples contained various amounts of feldspar, amphibole, biotite and groundmass, with rare quartz phenocrysts (Fig. 2). The groundmass was mostly fine-grained, but in some specimens, coarser-grained groundmass was present (Ündül, 2016).

2.1. Mineralogical and petrographic studies

X-ray powder diffraction (XRD) analyses were conducted on powdered specimens with a grain size less than 20 μm in order to determine their mineralogy. The powdered specimens were obtained by crushing and grinding the remnant parts of the cores following thin-section preparation (Fig. 1). X-ray diffraction measurements were made for 23 specimens with a Bragg-Brentano diffractometer (Bruker AXS D8) using Co Kalpha radiation. DIFFRACplus (BRUKER AXS) and the Rietveld software AutoQuan (GE SEIFERT) were used to quantitatively determine the mineral composition of each sample at the Institute for Geotechnical Engineering, Environmental Engineering and Clay Mineralogy in ETH-Zürich. The mineralogical compositions obtained from the quantitative mineralogical studies are named mass fractions throughout the remainder of the paper. Additionally, the loss-on-ignition values of the samples were determined gravimetrically by weighing powder specimens in ceramic crucibles before and after ignition at 1050 °C for 2 h.

Petrographic studies were completed using thin-sections, which were prepared from the saw-cut surfaces of samples that were prepared for CERCHAR tests (Fig. 1). Quantitative petrographic studies were conducted on digital images of the thin-sections obtained using a Nikon Digital Sight DS_U3 system (NIS Elements Imaging software 4.00) and

Table 1
Basic information of studied volcanic rocks.

Sampling coordinate	Sample numbers	Weathering grade[a]	Petrographic description
35T 400661.21 E, 4450847.39 N	1, 2	W I	Andesite
35T 402973.67 E, 4448300.38 N	3, 4	W II	Andesite
35T 403431.40 E, 4448425.81 N	5–7	W I	Andesite
35T 399175.94 E, 4440645.16 N	8, 9	W I	Andesite
35T 398477.17 E, 4446064.14 N	10, 11	W I	Rhyodacite
35T 410473.65 E, 4454542.72 N	12–14	W I	Andesite
35T 406926.19 E, 4452993.48 N	15–18	W I	Andesite
35T 395438.66 E, 4445049.84 N	19, 20	W II	Rhyodacite
35T 394804.23 E, 4440692.25 N	21–23	W I	Andesite

[a] According to ANON (1995).