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Investigación de las propiedades físicas y químicas de las cenizas volcánicas del Sangay en Ecuador

Investigation of the Physical and Chemical Properties of Sangay Volcanic Ash in Ecuador

Investigação das propriedades físicas e químicas da cinza vulcânica Sangay no Equador

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Resumen

Ecuador, rico en paisajes volcánicos, donde el volcán Sangay es uno de los más activos. En promedio, la nación experimenta cinco erupciones cada década, y las erupciones significativas del Sangay están documentadas desde 1628. Este estudio integral profundiza en las características de las cenizas del volcán Sangay. Se examinan meticulosamente los atributos físicos clave, como la gravedad específica, la densidad aparente, el contenido de agua, el índice de plasticidad, la distribución del tamaño de las partículas, la permeabilidad y la composición química, incluida la presencia de cuarzo, plagioclasa, hornblenda y minerales secundarios como óxidos y epidota. En particular, los análisis químicos destacan un alto contenido de sílex, plagioclasa de andesina y puzolana, lo que indica posibles aplicaciones en la producción de cemento. Utilizando un enfoque estructurado, se prepararon muestras del Parque Nacional Sangay mediante el método de división por riffles y se sometieron a una serie de pruebas basadas en las normas ASTM establecidas. Junto con el análisis de propiedades, se realizó una revisión exhaustiva de la literatura, que reveló las aplicaciones multifacéticas de la ceniza volcánica, especialmente en la estabilización de suelos, innovaciones en materia de adsorbentes y mejora de cementos geopoliméricos. En conclusión, los atributos únicos de la ceniza volcánica de Sangay subrayan su inmenso potencial en diversas aplicaciones ambientales y de ingeniería, lo que enfatiza la necesidad de continuar con la investigación para aprovechar todas sus capacidades.

Palabras clave: Ceniza volcánica; Volcán Sangay; Propiedades físicas; Propiedades químicas; Ecuador.

Abstract

Ecuador, rich in volcanic landscape where Sangay Volcano being one of the most consistently active among them. On average, the nation experiences five eruptions every decade, with Sangay's significant eruptions documented since 1628. This comprehensive study delves deep into the characteristics of ash from the Sangay Volcano. Key physical attributes such as specific gravity, bulk density, water content, plasticity index, particle-size distribution, permeability, and chemical composition, including the presence of quartz, plagioclase, hornblende, and secondary minerals like oxides and epidote, are meticulously examined. Notably, chemical analyses highlight a high content of silex, andesine plagioclase, and pozzolan, indicating potential applications in cement production. Using a structured approach, samples from Sangay National Park were prepared through the riffle splitting method and subjected to a series of tests based on established ASTM standards. Alongside the properties analysis, an extensive literature review was conducted, revealing the multifaceted applications of volcanic ash, especially in soil stabilization, adsorbent innovations, and geopolymer cement enhancement. Conclusively, the unique attributes of Sangay's volcanic ash underscore its immense potential in diverse engineering and environmental applications, emphasizing the imperative for continued research to harness its full capabilities.

Keywords: Volcanic Ash; Sangay Volcano; Physical Properties; Chemical Properties; Ecuador.

Resumo

Equador, rico em paisagem vulcânica, onde o Vulcão Sangay é um dos mais consistentemente ativos entre eles. Em média, o país experimenta cinco erupções a cada década, com as erupções significativas de Sangay documentadas desde 1628. Este estudo abrangente investiga profundamente as características das cinzas do vulcão Sangay. Os principais atributos físicos, como a gravidade específica, a densidade aparente, o teor de água, o índice de plasticidade, a distribuição do tamanho das partículas, a permeabilidade e a composição química, incluindo a presença de quartzo, plagioclásio, hornblenda e minerais secundários como óxidos e epidoto, são meticulosamente examinados. Notavelmente, as análises químicas destacam um elevado teor de sílex, andesina plagioclásio e pozolana, indicando potenciais aplicações na produção de cimento. Utilizando uma abordagem estruturada, foram preparadas amostras do Parque Nacional de Sangay através do método de riffle split e submetidas a uma série de testes baseados nas normas ASTM estabelecidas. Juntamente com a análise das propriedades, foi realizada uma extensa revisão da literatura, revelando as aplicações multifacetadas das cinzas vulcânicas, especialmente na estabilização de solos, inovações em adsorventes e melhoramento do cimento geopolimérico. Conclusivamente, os atributos únicos das cinzas vulcânicas de Sangay sublinham o seu imenso potencial em diversas aplicações de engenharia e ambientais, enfatizando a necessidade de investigação contínua para aproveitar todas as suas capacidades.

Palavras-chave: Cinzas Vulcânicas; Vulcão Sangay; Propriedades físicas; Propriedades químicas; Equador.

Introduction

Ecuador has approximately 55 active volcanoes, including Cotopaxi, Sangay, and Tungurahua, with an average of approximately five eruptions per decade. The Ecuadorian Geophysical Institute of the National Polytechnic School (IG-EPN) conducts constant surveillance of volcanic and seismic phenomena in Ecuador using remote sensing, geophysical monitoring, and field campaigns with the support of the management of the Parque Nacional Galápagos [1]– [3].

Located in the southern region of the Ecuadorian Andes, approximately 200 km south of Quito, Sangay Volcano is a highly active stratovolcano [4]. In fact, it holds the distinction of being the southernmost erupting volcano within the Northern Volcanic Zone of the Andes [5]. Sangay is noted for its continuous activity, punctuated by occasional periods of dormancy. Historical records indicate that it has undergone at least nine significant eruptions since 1628 [4]. The eruption on September 20, 2020, ejected between 1.5 and 5.0 million cubic meters of ash, producing an Strombolian height of eruption column that split into a higher, gas-rich cloud flowing east-southeast and a lower, ash-rich cloud moving west. The ash dispersal extended up to 280 km from the volcano [1].

Volcanic ash has various properties that make it suitable for various applications. The physical properties, mineral content, and chemical composition of volcanic ash are critical for its practical application. Overall, research on volcanic ash encompasses various disciplines and aims to improve our understanding of its properties, impacts, and potential applications. Therefore, the present work investigated the physical properties of Sangay volcano ash through an experimental investigation to describe its properties such as apparent specific gravity, bulk density, water content, plasticity index, liquid and plastic limits, particle size analysis, permeability, and unconfined compressive strength. In addition, a bibliographic analysis of different applications is presented.

Methodology

Sample Collection

For this study, samples were gathered from Sangay National Park in eastern Ecuador, where the Andes, Amazon, and Equator intersect [6]. The fieldwork was conducted in December 2021, focusing on the southeastern drainage area of the volcano. The targeted sampling area spanned a 2.5 km² radius around the crater of Sangay Volcano. Due to accessibility issues, a smaller area of

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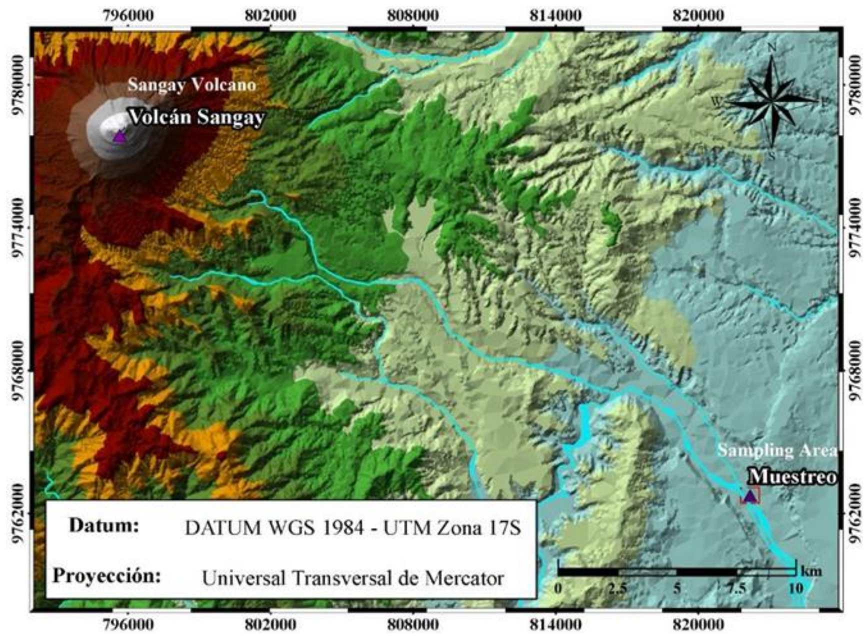
about 0.53 km² was selected (Fig. 1). From this area, four samples (C1, C2, M2, and M5) were collected, each weighing approximately 500 grams.

FIGURE 1: *Sampling area location in the vicinity of the Sangay volcano*



Sample Preparation and Test Procedures

Four samples were mixed and homogenized using riffle splitting to prepare volcanic ash samples for testing. This method is preferred because it provides unbiased and variance-minimized subsampling procedures [7]. Riffle splitting has been shown to perform well in terms of precision and accuracy compared to other sample-splitting methods [8]. The number of subsamples produced during the splitting process can be adjusted based on the desired level of reduction in sample mass [9]. In this study, a splitter with 20 chutes and two collection pans was used.

Subsequently, a series of tests was performed according to the following standards:

a. **ASTM D854:** Test for specific gravity of soil solids using a water pycnometer.
b. **ASTM C29:** Test for bulk density ("unit weight") and voids in aggregate.
c. **ASTM D2216:** Test for laboratory determination of water content.
d. **ASTM D4318:** Test for liquid limit, plastic limit, and plasticity index of soils.
e. **ASTM D422:** Particle size analysis of soils.
f. **ASTM D2434:** Test for permeability of granular soils (constant head).

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g. **ASTM 2166-06:** Test for unconfined compressive strength of cohesive soil.

The ash test results are presented in tables and graphs. Concurrently, the corresponding analyses and interpretations are elaborated in the conclusion section.

The collected samples primarily fall within the sand size range, specifically varying from coarse to very coarse particles (0.6 - 2 mm) as per the Wentworth classification [10]. Given the volcanic origin of these sediments, they were classified as coarse volcanic ash following Fisher's classification system [11].

Regarding mineral content (Fig.2), quartz was predominant (50% - 60%) in the samples. It is accompanied by a euhedral crystal form and tabular habit of plagioclase (10%–15%). Mafic minerals, mainly hornblende (10%–15%), were also identified in all the samples based on an elongated prismatic habit and vitreous to dull luster, black color. Oxides and epidote occurred as secondary minerals (5% - 10%). Iron oxides: magnetite and hematite are predominant, and iron hydroxides such as goethite and limonite minerals are also included. Finally, other accessory minerals are about 5% observed with yellow color, which could be sulfur, any variety of apatite, or jarosite.

Chemical analyses by X-ray diffraction and fluorescence spectroscopy confirms a high content of silex, andesine plagioclase and pozzolan (Table 1 and Table 2). Particularly, the presence of pozzolan (25.60%) on the Sangay ash allows the potential use of this ash on cement production.

TABLE 1: *Tables X ray Diffractometry Spectroscopy results*

Specimen	**SANGAY ASH**
Name	Cement - Standard
Time	8/17/2023
Quartz	0.57%
Gypsum	0%
Calcite	0.76%
Dolomite	1.30%
Andesine	55.18%
Illite	8.64%
Hornblende	2.81%
Puzzolane amorphous	25.60%
Cristobalite	1.62%
Calcite magnesian	1.49%

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Phlogopite	0.66%
Hematite	1.37%

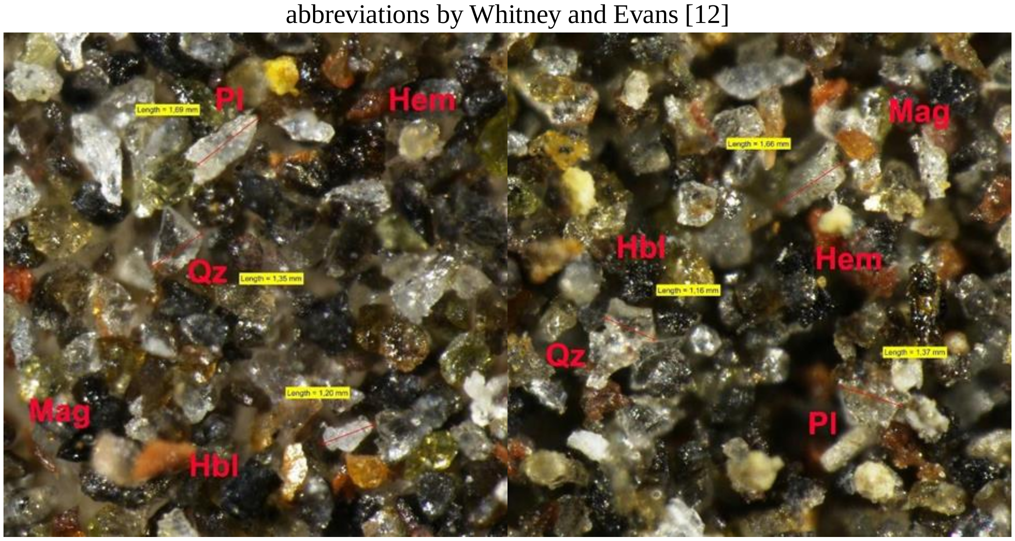
TABLE 2: *X ray Fluorescence Spectroscopy results*

Sum	85.600%	K_2O	1.785%	V_2O_5	0.044%
Compton	75.682%	TiO_2	0.905%	ZrO_2	0.027%
SiO_2	49.102%	P_2O_5	0.265%	CuO	0.023%
Al_2O_3	13.936%	SO_3	1.170%	Cr_2O_3	0.020%
CaO	7.021%	BaO	1.104%	ZnO	0.016%
Fe_2O_3	6.787%	SrO	1.102%	NiO	0.006%
Na_2O	3.209%	MnO	1.099%	Rb_2O	0.004%
MgO	1.954%	Cl	1.065%		

Discerning Patterns in the Utilization of Volcano Ash

The methodology employed entailed conducting a research investigation utilizing the Scopus database with a focus on Volcanic Ash Application. This method involves a systematic and rigorous search process aimed at retrieving scholarly papers and publications relevant to the potential use of volcanic ash with properties similar to those of the analyzed sample. Utilization of the Scopus database ensured a comprehensive and exhaustive search, enabling inclusion of a wide array of academic sources from diverse disciplines.

FIGURE 2: Mineral content of volcanic ash from Sangay (samples: a) C1M2T270 and b) C2T270). Mineral abbreviations by Whitney and Evans [12]



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Results and discussion

As shown in Table 3, the specific gravity and unit weight indicate the density of the material, whereas the water content and voids provide insight into its porosity. Particle size analysis helped understand the particle size distribution in the ash sample. The permeability measurement indicates the ability of the material to allow fluid flow, whereas the unconfined compressive strength indicates its mechanical properties.

TABLE 3: *Results of the physical properties.*

Nº	Test	Result
1	Specific Gravity	2.567 gr/cm^3
2	Unit weight	1.35 gr/cm^3
3	Voids	47.41%
4	Water Content	31.68%
5	Liquid Limit (LL)	Non Plastic
6	Plastic Limit (PL)	Non Plastic
7	Plasticity Index (PI)	Non Plastic
8	Permeability	5.3884X10-4 cm/s
9	Unconfined Compressive Strength	0.0054 N/mm^2
10	Passes percentage of sieve no.200	5.95%

To guide future research and explore potential applications, it is essential to consider the analyzed properties. For example, volcanic ash from Mount Sinabung exhibited physical properties such as a specific gravity of 2.62 g/cm^3, liquid limit (LL), plastic limit (PL), and a plasticity index (PI); with 13.80% passing through sieve no. 200. [12] conducted a study that demonstrated a gradual reduction in both the liquid limit and plasticity index by adding volcanic ash and rice husk. Specifically, the PI decreased from 26.33% up to 5.31% when additional materials like volcanic ash (2.5%) and rice husk ash (22.5%) were used. Regarding mechanical properties, a soil mixture composed of 75% soil and 25% volcanic ash achieved an optimal California Bearing Ratio (CBR) value of 15.48%. Furthermore, incorporating 25% of volcanic ash into the soil enhanced compressive strength, increasing it from an initial value of 1.38 kg/cm^2 to a final strength of 2.23

kg/cm². Additionally, an Unconfined Compression Test showed that the compressive strength (qu) of the original soil was 1.38 kg/cm², while the remolded soil had a reduced compressive strength (qu) of 0.58 kg/cm².

Research has also focused on the application of volcanic ash in soil stabilization. One study examined the use of volcanic ash and phosphoric acid for stabilizing soft soil and found that higher percentages of volcanic ash and phosphoric acid decreased the plasticity index (PI) and increased the unconfined compressive strength [13]. Other studies have explored the development of adsorbents using volcanic ash. For instance, one study prepared and tested CTAB-modified silica on the basis of volcanic ash to remove hazardous Cr (VI) anions, finding that the modified silica had a higher adsorption capacity than amorphous silica gel [14].

Volcanic ash has also been studied for its potential in improving geopolymer cement and concrete. Geopolymers are cement-free binders that can be developed using volcanic ash as a source material [15]. The elemental composition and mineral occurrence of volcanic ash influence its reactivity through polymerization, which can affect the mechanical properties of the resulting geopolymer concrete [16]. Research has shown that geopolymer concrete incorporating volcanic ash can exhibit increased strength compared to other types of concrete, such as fly ash concrete and normal OPC concrete [17]. The use of volcanic ash in geopolymer concrete also enhances compressive strength and decreases water absorption [18]. Additionally, the incorporation of volcanic ash into geopolymer cement and concrete can contribute to their sustainability by reducing the amount of Portland cement required [19].

[20] outlined various potential engineering applications for volcanic ash, particularly emphasizing the significance of pozzolan in concrete. The American Concrete Institute (ACI) Committee revised the guidelines and requirements of ASTM C 618 and CSA A23.5 standards, indicating that low-strength materials can be utilized as a substitute for cohesive granular materials in situations where settlement might pose issues [21]. Consequently, pozzolan, along with cement, water, and fine aggregate, has been employed in controlled fills with low strength, achieving compressive strengths varying from about 0.35 to 8.28 MPa (50 to 1200 psi).

Although the study of pozzolan properties is increasing, its use is not novel. Evidence suggests that the Romans utilized pozzolan since the mid-1st Century BCE and the mid-1st Century CE [22]., and possibly could have been employed by the Egyptian Empire [23]. Finally, its use in mining is being explored. Yowa [24] reported that pozzolans and pitchstone fines replaced cement by 10–

20% obtaining a comparable unconfined compressive strength (UCS) to make mine backfilling more environmentally friendly. Similar to Saudi Arabia [25] where after testing for UCS 7, 14, 28, 56, and 90 days, samples developed sufficient strength to be used in mine backfilling applications. Even the reuse of Waste Clay Brick fine particles could work with 5% partial cement replacement for material with a maximum compressive strength of 30 MPa [26]. Thus, it is suitable in rigid pavements, including applications as mixing old and new concrete, grouting and filling cavity holes.

The oxide compositions of the Sangay ash just meet the 70% for the total sum of SiO2 +A12O3 + Fe2O3 oxides. Nevertheless, [27] recommended Xray diffraction (XRD)-based technique instead of X-ray Fluorescence Spectroscopy (XRF) for determining ash content due to the first one is able to detect amorphous phases of silica and alumina.

Conclusion

In conclusion, the results of the analysis conducted on the volcanic ash sample provided valuable insights into its physical and mechanical properties. The specific gravity and unit weight values indicated that the material possessed a moderate density, whereas a relatively high void percentage suggested a considerable degree of porosity. The permeability measurements indicated a moderate fluid flow capacity, and the unconfined compressive strength reflected a relatively low mechanical resistance.

The outputs from this analysis, help as evidence that volcanic ash exhibits unique characteristics that render it suitable for various applications. Previous research has demonstrated its potential for soil stabilization, where its incorporation leads to a reduction in the plasticity index and an enhancement in the unconfined compressive strength. In addition, volcanic ash has shown potential as an porous material, particularly for filtering hazardous Cr (VI) anions, because of its high adsorption capacity when modified with CTAB.

Furthermore, volcanic ash has garnered attention in the development of geopolymer cement and concrete owing to its reactivity during the polymerization process and its contribution to the increased strength and reduced water absorption in the resulting geopolymer concrete. This application also presents an opportunity to enhance sustainability by reducing reliance on Portland cement using pozzolans.

These findings contribute significantly to the understanding of volcanic ash properties and open avenues for further research and exploration of its potential applications in various fields such as mining. The unique attributes of volcanic ash have acquired interest in diverse scientific domains, prompting investigations into its use in soil stabilization, adsorbents, geopolymer cement, and concrete. Consequently, novel investigation endeavors should focus on exploring and optimizing the utilization of volcanic ash, unlocking its full potential in sustainable engineering and environmental applications.

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