Thermal, structural and mechanical characterization of the whitish Arequipa Airport Ignimbrite

F S Espinoza, M Horn, M M Gomez and J L Solis
Faculty of Science, Universidad Nacional de Ingeniería, 15333, Lima 25, Peru
Email: jsolis@uni.edu.pe

Abstract. The white unit of Arequipa Airport Ignimbrite is a pyroclastic rock that emerges in the deposits of Arequipa and is used as a construction material since colonial times and locally called “sillar” or “ashlar”. The thermal conductivity and thermal diffusivity measured according to ASTM C 177 and Ångström’s method were 0.27 W/mK and 5.67x10^{-7} m^2/s, respectively. The compressive strength and water absorption were 8.92 MPa and 17.2 %. The main crystalline phases of the ignimbrite are plagioclase, cristobalite, sanidine and biotite. The white ignimbrite has good thermal insulation and good mechanical properties.

1. Introduction
The Arequipa Airport Ignimbrite (AAI) is one of the 4 types of ignimbrite that it is located in Arequipa: Río Chili Ignimbrite (RCI), La Joya Ignimbrite (LJI), Arequipa Airport Ignimbrite (AAI), and Yura Tuffs (YT) [1]. In particular the white AAI is used as construction material and as a decorative element from pre-Hispanic times [2]. The knowledge about thermal conductivity of Peruvian ignimbrites used in the construction is limited. In recent years, the temperature in the highlands of Peru during winter decrease drastically during the nights to less than -20°C. These areas have a lot of sunshine during the day, so the sun could use for heating the buildings during the day and keeping temperature at a constant level during the night. It is very important to use bricks with low thermal conductivity to build in the Peruvian highlands. In this paper the thermal, structural and mechanical properties of white AAI were studied. The thermal conductivity measurement was performed in a homemade apparatus called “LAMBDA-UNI” based on the guarded hot plate method. This apparatus was constructed considering the norm ASTM C177 [3, 4]. The thermal diffusivity was measured by an assembled equipment base on Ångström’s method. Also, X-ray diffraction (XRD) and scanning electron microscopy (SEM) was performed to determine the minerals and the morphology in the white AAI.

2. Methods
The characterization methods used for measure the thermal conductivity and diffusivity, compressive strength, morphological and structural properties of the white AAI are presented.

2.1. Thermal conductivity
The thermal conductivity was measured using the LAMBDA-UNI, an apparatus constructed following the norm ASTM C 177 based on the guarded hot plate method [5]. This apparatus is composed (see Fig. 1) of a hot plate in the central part, two cold plates upper and lower to the hot plate, a refrigeration system for the cold plates, two heat sources for the hot plate, and a data acquisition system. The hot plate is composed of two parts: the measurement zone is a central plate with diameter of 150 mm and a guard
ring surrounding with an external diameter of 375 mm, made of the same material. Every part is heated by an independent external due that an electrical resistance is incorporated at their interior in each of these parts. Two identical samples are required, one is 16.35 cm x 16.8 cm x 5.62 cm and the other is 16.29 cm x 17.06 cm x 5.35 cm. The samples were oven-dry for one day at 95 °C.

Figure 1. The schematic of the guarded hot plate apparatus (LAMBDA-UNI).

The steady-state requires that the insulating material be in equilibrium with its surroundings in order to obtain an accurate thermal conductivity. Once the system has reached thermal equilibrium, the thermal conductivity is calculated from:

$$\lambda = \frac{Q \cdot e}{A \cdot (\Delta T_1 + \Delta T_2)}$$

where $\lambda$ is the thermal conductivity of the specimen (W/ m K), $Q$ is the heat transfer ratio of the specimens (W) that was deduced from the power supplied to the resistors for heating, $\Delta T_1$ and $\Delta T_2$ represents the differences in temperature in the stationary state between the central hot plate ($T_h$) and the top and bottom cold plates ($T_{c1}$ or $T_{c2}$) (K), $e$ is the average thickness of the specimens (m), and $A$ is the area of the measurement zone (m²). Figure 2 shows the frontal view of the central plate and its two components: the measurement zone and the guard.

Figure 2. Hot plate: (a) front view of an internal hot plate, (b) hot plate sandwich type, the measurement zone has a diameter of 150 mm and a guard external diameter of 375 mm. The air gap that separates the two is 1 mm.
2.2. Thermal diffusivity measurements

Ångström’s method has been used to quantify the thermal diffusivity of white AAI via measurement in steady-state using AC heating of thermal waves propagating through a cylinder sample, as shown in the schematics in Fig. 3. The cylinder sample has a diameter of 150 mm and the thermal Insulation material a guard external diameter of 305 mm. The air gap that separates the two is 0.8 mm.

![Schematics of the experimental set up for thermal diffusivity measurement.](image)

With heat loss, the one dimensional heat diffusion equation can be rewritten as

\[
\frac{1}{\alpha} \frac{\partial T}{\partial t} + h T = \frac{\partial^2 T}{\partial x^2}
\]  

(2)

Where \(\alpha\) is the thermal diffusivity in \(\text{m}^2/\text{s}\), \(h\) is the heat loss coefficient and \(T\) is the temperature in K. The diffusivity is obtained from the fitting the two temperature curves \(T(x_1, t)\) and \(T(x_2, t)\):

\[
\alpha = \frac{(x_1 - x_2)^2}{2\Delta t} \left( \frac{1}{\ln \left( \frac{M_1}{M_2} \right)} \right)
\]  

(3)

Where \(x_1\) and \(x_2\) are the position where the temperatures are measured, \(M_1\) and \(M_2\) are the amplitudes of the first and second temperature curve and \(\Delta t\) is the time by which the second curve lags behind the first.

2.3. Mechanical properties.

For the mechanical test, 5 samples of the white AAI were used. The dimensions of the white AAI were cut to approximately 15.0 cm x 16.0 cm x 26.0 cm according to the Peruvian Edification Technical Norm E.070. To improve parallelism and flatness in the compression area of the samples a layer of gypsum-cement ratio of 1: 2 was used. They were oven-dry at 100 °C for 24 h. The tested sample is placed between two plates, so that the pressure is distributed homogenously in the exposed areas and the force at break is registered when adobe breaks.

The test of water absorption for 24 h indicates the absorption capacity of the samples when they reach a state of saturation according to NTP 399.613:

\[
\text{Absorption} \% = 100 \left( \frac{W_b - W_d}{W_d} \right)
\]  

(4)

Where \(W_b\) is the constant dry weight (kg) and \(W_d\) is the saturated weight (kg).
2.4. Structure and morphology characteristics.
The crystal structure and surface morphology of the white AAI was characterized by X-ray diffraction using a D8 Advance Bruker diffractometer operated with Cu Kα radiation and by SEM using a HITACHI model SU8230 instrument operated at 40 kV, respectively.

3. Results and Discussion

The thermal conductivity value of the white AAI of $0.27 \pm 0.045$ W/m K with 0.2 % water content was determined. The thermal diffusivity determined of the white AAI was $5.67 \times 10^{-7} \pm 0.46 \times 10^{-7}$ m$^2$/s with 10.54 % water content.

The compressive strength obtained of the white AAI was 8.92 MPa. The absorption value was determined for 24 h saturation and the average value of 17.2 %. According to the Peruvian norm E.070, due to the results of unit compression resistance of the white AAI, it has similar properties to a brick masonry unit type II.

The X ray diffractogram of white IIA is presented in Figure 4. The XRD study (Fig. 4) showed the presence of plagioclase 39% wt (anorthite 22 % and albite 17 %), cristobalite 29 %wt, sanidine 28 % wt and biotite 4 %wt.

![Figure 4](image)

Figure 4. X-ray powder diffraction patterns for the WU-AAI. The predominantly detected crystalline phases are cristobalite (c), sanidine (s), plagioclase (p) (albite and anortithe) and biotite (b).

White AAI specimens of 1.0 cm x 1.0 cm x 1.0 cm were cut for analysis of their morphology with SEM. Figure 6 shows that white AAI is porous. Figure 5 shows the micrography of the WU-AAI. This system presents cavities of diverse sizes, among which the smallest cavities are less than 1 µm and the largest are on the order of 12 µm. Furthermore, the porosity of WU-AAI is clearly shown, and it can be seen how the particles interact with each other.
4. Conclusions
The average thermal conductivity and diffusivity of white IAA is $0.27 \pm 0.045$ W/m K and $5.67 \times 10^{-7} \pm 0.46 \times 10^{-7}$ m$^2$/s, respectively. The main components (minerals) present in the white AAI were plagioclase (anortithe 22 %, albite 17 %), cristobalite 29 %, sanidine 28 %, and biotite 4 %.

The average value compression resistance to unity of the white AAI was 8.92 MPa according to the Peruvian norm E.070. It has similar properties as a brick masonry unit type II. The absorption value was determined for 24 h saturation and the average value was 17.2 %, which presents characteristics similar to the masonry units used outdoors according to the Peruvian norm E.070.

The internal morphology of white AAI is porous and it contains particles of different sizes and encapsulated air bubbles. The results show that the thermal and mechanical properties of the white AAI can be suitable for the construction of houses in high Andean areas.

Acknowledgments
This work was carried out under the auspices of the Peruvian National Council for Science and Technology (CONCYTEC) under the contact N° 122-2018-FONDECYT – SENCICO.

References
[1] P. Paquereau, J. Thouret, G. Wörner, and M. Fornari, *J. Volcanol. Geotherm*, vol. 150, 2006
[2] A. Bustamante, F. Capel, F. Barba, P. Callejas, R. Guzmán and A. Trujillo, Mössbauer studies of raw materials from Misti volcano of Arequipa (Peru) for its potential application in the ceramic field, *Hyperfine Interact* (2009) 190:115–119
[3] D. Salmon, Thermal conductivity of insulations using guarded hot plates, including recent developments and sources of reference materials, *Meas. Sci. Technol.* 12 (2001) R89–R98
[4] American Society for Testing and Materials 2004 ASTM C 177-04: Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot-Plate Apparatus
[5] J.M. Piñas, L. Lira, M. Horn, J.L. Solis and M.M. Gómez, Influence of *Stipa ichu* on the thermal and mechanical properties of adobe as a biocomposite material, *J.Phys. Conf Ser* 1433 (2020) 012003
[6] W. N. dos Santos, J. N. dos Santos, P. Mummery, and A. Wallwork, Thermal diffusivity of polymers by modified Angström method, Polymer Testing, vol.29, p 107-112, 2009

[7] Y. Zhu, Heat-loss modified angstrom method for simultaneous measurements of thermal diffusivity and conductivity of graphite sheets: The origins of heat loss in Angström method. Int. Heat Mass Transfer, vol. 92, p. 784–791, 2015

[8] Peruvian masonry technical standard E.070, 2006