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UTILIZATION OF LOCAL QUARRY WASTE AS RAW MATERIAL IN THE PRODUCTION OF INSULATING FIREBRICKS

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ABSTRACT: Quarry waste from Barangay Binaliw, Cebu City, Philippines, was evaluated for its potential to produce insulating firebricks. The raw material, containing quartz, anorthite, and chlorite, was first ground in a ball mill and then dried in an oven for 24 hours. After the drying process, the material was then passed through a mechanical sieve sized at 150 microns. The sieved particles were then mixed with water prior to being pressed in a metallic mold at 20 MPa by a hydraulic press. The green bricks produced were then dried again for 24 hours in a drying oven and then fired in a muffle furnace to final temperatures of 800 °C, 900 °C, 1000 °C, 1100 °C, 1200 °C, and 13000C at a heating rate of 50 °C/min. These temperatures were held for 2 hours after being reached by the furnace. XRD characterization of the fired samples revealed the final mineralogical composition of Quartz, Anorthite, and Maghemite. ASTM standardized tests were conducted to assess bulk density, porosity, shrinkage, and crushing strength. The results identified 1100°C as the optimal firing temperature, yielding bricks with a bulk density of 1.83 g/cm³, a porosity of 32.5%, and a crushing strength of 23.53 MPa. Thermal instability was observed at 1200°C, where there was spalling, and at 1300°C, the bricks completely melted. This study demonstrates the feasibility of converting quarry waste into high-performance insulating firebricks, contributing to sustainable construction practices and the circular economy by re-purposing an environmental pollutant into a valuable industrial material.

Keywords: Quarry waste, Insulating Fire bricks, Anorthite bricks, Refractories

1. INTRODUCTION

Quarry waste can have significant environmental impacts, including air and water pollution, habitat destruction, soil erosion, and biodiversity loss. Dust, gases, and fine particles from quarrying activities often degrade local air and water quality. Improper waste disposal can lead to soil contamination and damage to ecosystems. The communities near quarries also face health risks and disruptions due to vibrations, noise, and dust from operations. Quarry rehabilitation and improved waste management strategies are critical to mitigate these impacts[1].

Several studies have explored the utilization of industrial, construction, agricultural, quarry, and even refractory waste itself in the production of not only insulating refractory bricks but also various sustainable building materials with the aim of reducing environmental impact while enhancing brick properties. For instance, one study involves combining waste materials like quarry dust with other industrial by-products, such as fly ash, to produce refractory bricks with improved insulating capabilities[2]. These materials not only provide thermal insulation but also maintain mechanical strength, making them suitable for high-temperature applications like kilns and furnaces. Other studies highlight that incorporating waste materials in refractory bricks can enhance properties such as porosity and heat retention[3-4]. For example, when combustible wastes like rice husk are mixed with locally sourced clay, they contribute to both thermal insulation and lower production costs. Similarly, the conversion of quarry waste into masonry blocks using alkali-activated rice husk ash and eggshell ash as binders highlights the potential of combining industrial by-products to create durable and eco-friendly building materials [5].

In the field of geotechnical and construction engineering, various studies have shown the potential of recycled and low-energy materials, such as crushed concrete and lime-based binders, to improve soil properties effectively while reducing reliance on non-renewable resources[6-11]. The re-usability of construction waste, like crushed concrete, enhances soft clay soils by increasing their shear strength and lowering compressibility, which highlights both mechanical advantages and environmental benefits [6]; or the lime pile techniques and recycled aggregates that reduce carbon emissions and waste[7]. Few studies have investigated and shown the potential of incorporating recycled refractory bricks as coarse aggregates by improving their mechanical properties[8-9]. Finally, research into silicate binders derived from silica refractory brick waste provides insights into the mechanical and structural improvements achievable through the use of industrial waste[10].

In the context of refractory engineering, this study applies similar principles to explore the potential of local quarry waste as a sustainable resource in refractory brick production.

The distinction between insulating firebricks and high-temperature refractory bricks revolves around their structure and purpose. High-temperature refractory bricks are denser, more durable, and designed to withstand extremely high temperatures, often over 1600°C, making them ideal for furnace linings where mechanical strength and resistance to heat and wear are critical[12]. Insulating firebricks, on the other hand, are lightweight and highly porous, providing thermal insulation and preventing heat loss in applications with moderate temperatures. They are commonly used for heat insulation in Industrial applications today.

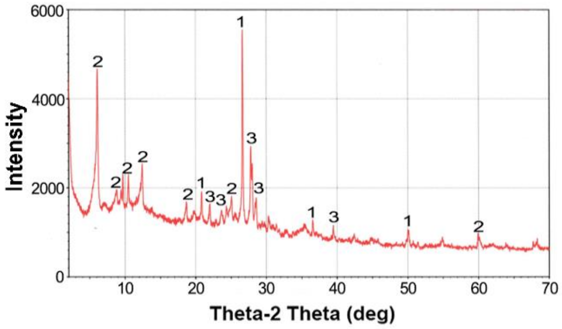

Fig. 1 XRD spectra of local quarry waste. The peaks labeled “1” indicate Quartz; “2” indicate Chlorite; “3” for Anorthite

There have been a number of studies on the production of Anorthite-based ceramics, with each having distinct additives[13-16]. Low-alkali clay, fire clay, sawdust, and paper waste were used as raw materials for the production of suitable insulating firebricks that were stable up to 1100 °C [15]. Despite the variety of admixtures, it can be stated that Anorthite, together with quartz, is an appropriate raw material for the production. Local quarry waste from Cebu City, Philippines, was taken from a site where the crushing, grinding, and washing of soil aggregates were operationally done on a daily basis. Dust, clay, and silt, which comprise the local quarry waste, were extracted and analyzed for their initial chemical and mineralogical composition. Despite the relatively low amount of Alumina, as seen on Table 1, the XRD spectra in Fig. 1 revealed the presence of Quartz, Anorthite, and Chlorite. With the exception of Chlorite, these minerals have suitable properties for refractory applications. The high SiO_2 content provides structural integrity and thermal stability, while the presence of Al_2O_3 supports the formation of anorthite, a calcium aluminum silicate known for its excellent thermal insulation properties. Additionally, fluxing agents such as CaO, MgO, and Fe_2O_3 reduce the sintering temperature, promoting densification and improving the brick's mechanical strength. During firing, the transformation of chlorite into maghemite further enhances the material's durability and heat resistance. These inherent properties ensure that the firebricks meet the demands of industrial applications, offering a lightweight, thermally efficient, and stable material.

Previous studies have investigated the use of industrial and construction waste, such as fly ash, rice husk ash, eggshell ash, and refractory brick waste, in producing insulating and high-temperature firebricks. These works often focused on improving properties like thermal insulation, mechanical strength, and porosity by partially replacing conventional materials. However, the use of quarry waste as the main raw material for firebrick production has not been fully explored. This study addresses this by utilizing quarry waste from Barangay Binaliw, Cebu City, as the sole raw material and analyzing its mineralogical transformations. It highlights the roles of anorthite, quartz, and maghemite in enhancing the firebricks' properties. Unlike earlier studies, this research systematically examines the effects of firing temperatures from 800°C to 1300°C, identifying 1100°C as the optimal firing temperature.

Table 1: Chemical composition of local quarry waste

Quarry Waste	
Chemical Composition	%Wt
SiO_2	43.7
Fe_2O_3	28.8
Al_2O_3	11
MgO	7
CaO	6.49
K_2O	3.43
TiO_2	1.99
MnO	0.87
SO_3	0.54
P_2O_5	0.32
SrO	0.3
ZnO	0.22
NiO	0.19
CuO	0.15
Cl	0.08
Rb_2O	0.03

The study begins with an analysis of the quarry waste's chemical and mineralogical composition, identifying its suitability for refractory applications. The materials and methods section details the preparation of the raw materials, the green brick formation process, and the firing schedule, with temperatures ranging from 800°C to 1300°C. Experimental tests were conducted to evaluate the fired bricks' physical and mechanical properties, including bulk density, apparent porosity, volume shrinkage, and cold crushing strength. The results and discussion explore the phase transformations occurring at different firing temperatures, the implications for material stability, and comparisons with industry standards. Finally, the study concludes by highlighting the optimal temperature range for stable brick production and discusses the potential environmental and industrial applications of this approach. By transforming environmental waste into an industrial material, this research supports circular economy principles, reduces the demand for commercial resources, and opens new pathways for sustainable material development in industrial applications. This provides a sustainable solution to manage quarry waste and transform it into valuable insulating firebricks, contributing to both environmental protection and material innovation.

2. RESEARCH SIGNIFICANCE

The production of insulating firebricks is important for industrial applications because of their lightweight structure, thermal insulation, and ability to reduce heat loss. This study addresses the issue of quarry waste accumulation in Barangay Binaliw, Cebu City, by converting it into useful insulating firebricks. Quarry waste, which causes habitat destruction, soil erosion, and pollution, is utilized in this research to produce firebricks, reducing environmental problems and supporting sustainable practices. This also decreases the use of non-renewable materials like fireclay and kaolin, contributing to the circular economy.

The suitability of quarry waste comes from its mineral content, particularly anorthite and quartz. Anorthite, a calcium-aluminum silicate, provides good thermal stability and low thermal conductivity, which are ideal for insulating firebricks. Quartz improves the mechanical strength and stability of the material during firing. Together, these minerals help produce firebricks with improved properties, including better bulk density, reduced porosity, and increased cold crushing strength.

The study developed a method to use quarry waste effectively, including grinding, sieving, pressing, and firing at controlled temperatures. The results showed that 1100°C is the best firing temperature for stable performance. This research offers a practical solution for producing insulating firebricks for kilns, furnaces, and other applications. It also serves as a model for other regions with similar waste issues, turning environmental problems into industrial resources. By combining sustainability with material development, this study supports cleaner environments and advances insulating firebrick production.

3. MATERIALS AND METHODS

3.1 Raw Material Preparation and Characterization

Quarry waste was obtained from the quarrying operations of a local soil aggregate company in Barangay Binaliw, Cebu City, Philippines. The collected wastes were first air-dried for 3 days and then dried in a drying oven at 110 °C for 24 hours. Dried samples were then crushed and ground by a ball mill and sieved in a mechanical vibrating sieve to sizes of less than 150 microns.

From Table 1, wavelength dispersive x-ray fluorescence spectroscopy analysis of the raw material revealed that the quarry waste had relatively high SiO_2, yet low in Al_2O_3. Fe_2O_3, MgO, CaO, TiO_2- which serve as fluxing agents- comprise 44.28% while the minor constituents comprising K_2O, MnO, SO_3, ZnO, NiO, CuO, Cl, Rb_2O contribute to a total of 5.51% of the whole sample.

The values of the composition in Table 1 dictate the type of firebrick that can be produced from the raw material. Unlike the related studies. The Alumina content is relatively lower than Silica – Silica making up most of the raw material by %wt – which prompted the authors to produce insulating firebricks instead of their high temperature refractory counterparts[13], [15].

X-ray diffraction pattern of the raw material is illustrated in Figure 1, which indicates the presence of Quartz, Chlorite, and Anorthite based on the intensity peaks at d = 3.34 A^0, 14.53 A^0, and 3.21 A^0, respectively. The labels – “1”, “2”, “3” in Fig. 1 are the minerals quartz, chlorite, and anorthite, respectively.

3.2 Mixture Proportions

In the production of green bricks, the dried, ground, and sieved Binaliw clay was mixed with distilled water in a mixer for 5 minutes. The clay-to-water ratio was 10:1. For each green brick produced, 250g of the clay-water mixture was placed in a metallic mold and compacted by a hydraulic press machine at a pressure of 20 MPa and held for 1 min. The dimensions of the green bricks produced were 5.2cm x 5.2cm x 5.2cm. For certain high-alumina and basic refractory materials, compaction pressures of 100 MPa to 180 MPa are used[17]. However, for insulating firebricks, 20 MPa is deemed suitable. This lower pressure is relevant for lightweight and thermally insulating firebricks, where excessive densification would negatively impact their insulating properties.

3.3 Firing Parameters

Prior to firing in a muffle furnace, the recently produced green bricks were dried in a drying oven for 24 hours. The firing temperatures were 800^0C, 900^0C, 1000^0C, 1100^0C, 1200^0C, and 1300^0C. That is, for a firing temperature of 8000 °C, a set of green bricks was fired in the programmable muffle furnace from 520 °C to 8000 °C at a heating rate of 50 °C/min. The firing temperature was held for 2 hours after it was reached. After 2 hours, the bricks were allowed to cool naturally within the furnace chamber until their temperature lowered to the initial chamber value of 520 °C. This procedure was repeated for the remaining temperatures of 9000 °C, 10000 °C, 11000 °C, 12000 °C, and 13000 °C.

These firing temperatures were selected to study the effects of sintering on the thermal and structural transformations of the bricks. At around 573°C, quartz undergoes a phase transition from α-quartz to β-quartz, which affects the bricks' structural stability and thermal performance. Chlorite decomposition begins at approximately 600°C[18], releasing Mg and Fe ions that help form maghemite, improving the bricks' durability and resistance to heat. Between 900°C and 1100°C, anorthite, a key phase for thermal insulation, forms through solid-state reactions.

As revealed in the Results and Discussion section, the range of 800°C to 1100°C provides the optimal conditions for densification and phase transformations without causing significant melting or structural damage. At 1200°C and 1300°C, the bricks were tested to their limits, where issues like spalling, cracking, and complete melting were observed, determining the operational temperature limits for the insulating firebricks.

3.4 Test Parameters

The tests were conducted on every brick produced at each of the firing temperatures. That is, each set of The bricks produced at the different firing temperatures were tested for their physical and mechanical properties. Each set of bricks produced at the different firing temperatures was tested for its physical and mechanical properties and mineralogical composition. The physical and mechanical properties tests were all performed 24 hours after firing to ensure sample stability. All tests were conducted on three replicate samples for each firing temperature. For the physical properties, bulk density, apparent porosity, and volume firing shrinkage were determined. ASTM C20[19] was the standard test used for the determination of the aforementioned properties. The standard used the boiling water method by weighing the dry brick, immersing it in water, and calculating the bulk density using the volume of water displaced.

The bulk density measured was the mass per unit volume, including the pores. The bulk density can be corroborated with the apparent porosity, which is the percentage of open pores in the brick. The apparent porosity was calculated using the same boiling water method by comparing the dry, saturated, and submerged weights of the brick.

The volume firing shrinkage assessed the reduction in brick volume after firing. This was

calculated using ASTM C326[20] by measuring the dimensions of the green and fired bricks, then determining the percentage of shrinkage.

The cold crushing strength, which is a mechanical property of the bricks, evaluates their mechanical strength under compressive load. This was determined by recording the maximum load imparted by the hydraulic compression machine on the brick upon fracture. This was done in accordance with ASTM C133[21]. Mineralogical compositions were determined through X-ray diffraction operating at 40kV and 30 mA using Cu radiation. Samples were scanned from 2º to 70º(2θ) at a step size of 0.02º. Chemical compound determination was done through wavelength dispersive x-ray fluorescence.

4. RESULTS AND DISCUSSION

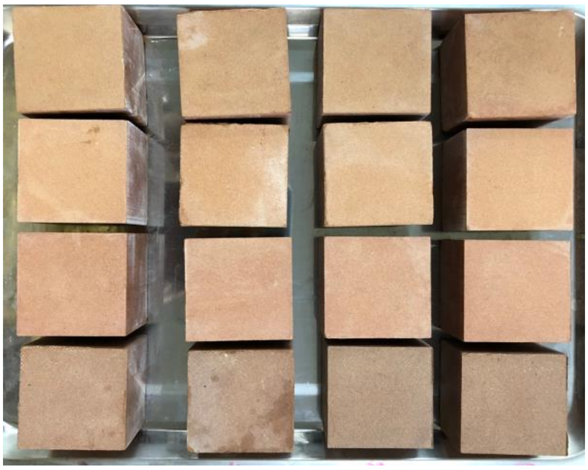

Fig. 2 Fired bricks at 800 °C, 900 °C, 1000 °C, 1100 °C. Bricks are arranged per row with the first row fired at 800 °C; the second row fired at 900 °C, the third row fired at 1000 °C, and the fourth row fired at 1100 °C.

Fig. 2 shows the end products of the green bricks fired at 800 °C, 900 °C, 1000 °C, and 1100 °C. It can be noticed that as the firing temperature increased, a more reddish-brown hue is achieved at higher temperatures, with the brick fired at 1100 °C having the most intensity. The increasing intensity of the reddish-brown color from 800°C to 1100°C indicates the formation of iron oxides, likely from the breakdown of chlorite, which contains iron. As chlorite decomposes, it releases iron that can oxidize to form maghemite (γ-Fe_2O_3), a reddish-brown iron oxide[22]. This matches with the presence of maghemite observed at 1100°C in the XRD analysis in Fig. 7. This iron oxidation process is responsible for the deepening color intensity. Unfortunately, at 1200 °C, the fired bricks turned dark black as seen on

Fig. 3 Bricks fired at 1200 °C

Fig 3. Multiple cracks can be seen on the surface of the bricks as well as spalling. The blackening could be due to further reduction of iron oxides or a change in the oxidation state of the iron. Under high temperatures and possibly limited oxygen availability, maghemite or other iron oxides could reduce to wüstite (FeO) or even metallic iron, both of which are darker.

At a firing temperature of 1200 °C, significant thermal expansion or phase changes caused internal stresses within the bricks, leading to cracks and spalling. Spalling occurs when internal stresses exceed the material's strength, causing layers to flake off[23]. This could also be due to excessive shrinkage as volatile components are driven off or as phases like anorthite and quartz begin to undergo significant changes. The breakdown of minerals, along with uneven thermal distribution, could have caused some areas to expand more than others, leading to an irregular surface[23].

Fig. 4 Bricks fired at 1300 °C completely melted on the alumina saggar

By 1300°C, as seen in Fig. 4, the brick mixture reached the temperature where complete melting occurred. Quartz (SiO_2) has a melting point around 1710°C, but anorthite ($CaAl_2Si_2O_8$) can start to soften and melt at lower temperatures, especially in the presence of other materials[18]. The melting behavior of the mixture indicates that a eutectic or near-eutectic reaction occurred, where components of the brick began to form a liquid phase[24]. This caused the brick to lose structural integrity and thus completely melt.

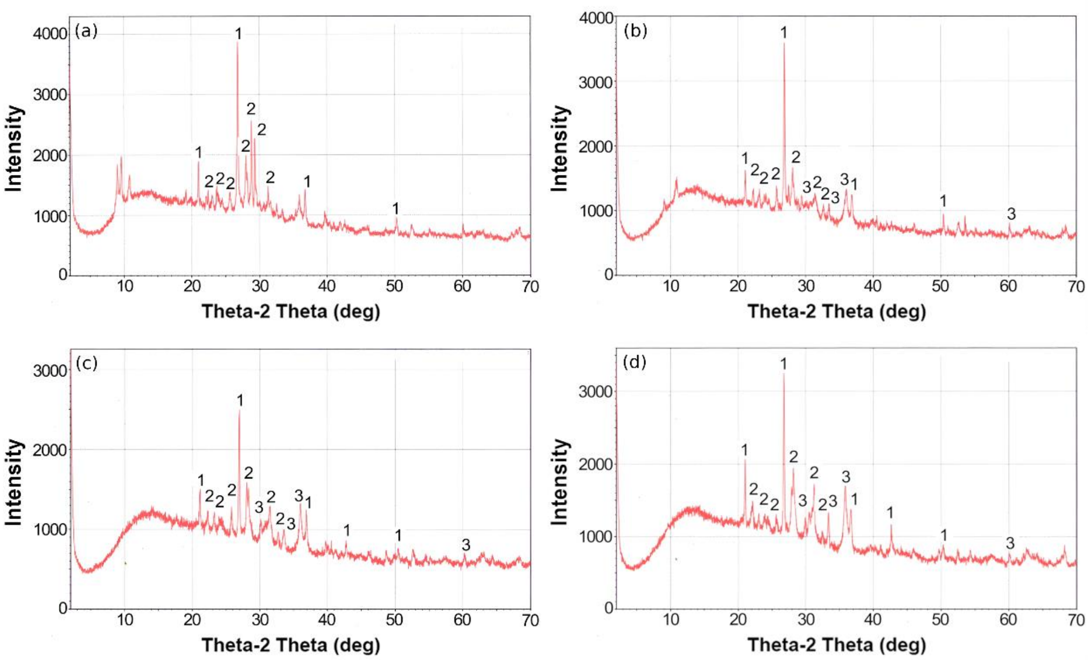

Fig. 5 XRD spectra of fired bricks. (a)800°C, (b)900°C, (c)1000°C, (d)1100°C

Fig 5(a)-(b) illustrates the XRD spectra of the fired bricks at the different firing temperatures of 800 °C, 900 °C, 1000 °C, and 1100 °C. The phase changes and crystalline phases detected at different temperatures revealed the following trends. The intensity peaks are tabulated in Table 2. The unfired bricks revealed the presence of quartz, chlorite and anorthite at the different peaks of 3.34 A°, 14.53 A°, and 3.21 A° respectively. At this initial firing stage, which is less than 800 °C, no significant densification has occurred. As revealed in Fig. 5(a) and Table 2, Chlorite has already disappeared at 800 °C, which indicates its decomposition. This process possibly released Fe and Mg ions, contributing to further reactions[18].

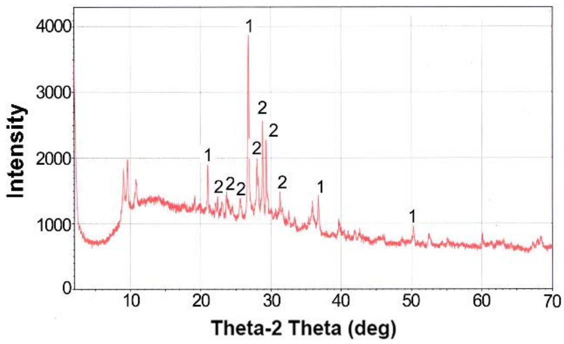

Fig. 6 XRD spectra of bricks fired at 800°C detected the presence of Quartz and Anorthite based on the intensity peaks at d = 3.33 A⁰ and 3.19 A⁰, respectively

The slight shift in the d-spacings of anorthite and quartz suggests the onset of thermal expansion. It could be possible that there are already traces of maghemite, but they may exist in small traces that XRD imaging is not capable of detecting. At 900 °C, Maghemite appears in the XRD spectra, suggesting some iron-containing phase transformations while quartz and anorthite remain.

The Fe ions released during the decomposition of Chlorite have oxidized when the firing temperature reached 900 °C, thus forming Maghemite. This formation of a new phase suggests that oxidation reactions are prominent, which could be linked to diffusion mechanisms within the solid matrix[25]. The occurrence of grain growth and further densification can be justified by the slight shift in peaks of anorthite and quartz. The same phases can be observed at 1000 °C, but the slight shifts in peak position from 3.32 A° to 3.31 A° for quartz and 3.18 A° to 3.17 A° for anorthite suggest that minor changes in crystallinity or phase interactions still continue to occur. The persistence of maghemite, with a d-spacing of 2.50 A° across both temperatures of 1000°C and 1100°C indicate structural stability. At 1000°C, quartz and anorthite continue so shift its peaks indicating that the material is expecting thermal expansion. Finally at 1100 A°, the phases remain the same, indicating stability.

Table 3 summarizes the mineralogical composition of pre-fired and fired bricks. Except for the green bricks fired at 800°C, the final mineralogical compositions were Quartz, Anorthite, and Maghemite. At 800°C, Anorthite, which is a Calcium Aluminum Silicate had already reacted with free Silica to form more plagioclase minerals - Anorthite being one of them- thus producing more Anorthite in the process. Fig 6 shows the XRD spectra of the bricks fired at 800°C.

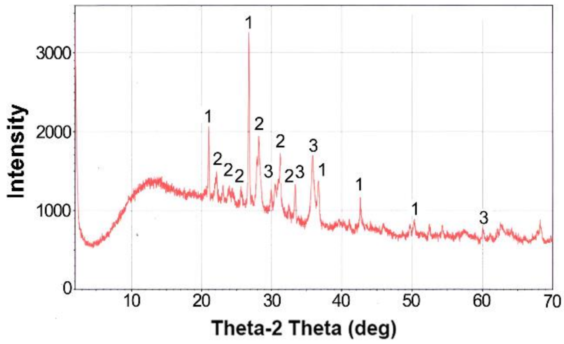

Fig. 7 XRD spectra of bricks fired at 1100°C. Quartz, Anorthite, and Maghemite based on the intensity peaks at d = 3.33 A⁰, 3.17 A⁰, and 2.50 A⁰ respectively.

Table 2 XRD peaks of unfired and fired bricks

Temperature(°C)	Mineral phases	d(A°)
	Quartz	3.34
Unfired	Chlorite	14.53
	Anorthite	3.21
800	Quartz	3.33
	Anorthite	3.19
	Quartz	3.32
900	Anorthite	3.18
	Maghemite	2.50
	Quartz	3.31
1000	Anorthite	3.17
	Maghemite	2.50
	Quartz	3.33
1100	Anorthite	3.17
	Maghemite	2.50

The decomposition of Chlorite, which is a Magnesium Iron Aluminum Silicate Hydroxide, starts at around 600°C[26]. Despite this temperature being lower than 800 °C, Maghemite was only found starting at 900 °C up to the maximum temperature of 1100 °C. This process loses water and releases Iron, which eventually can oxidize to form Maghemite as seen on the XRD spectra of Fig. 7. XRD patterns for bricks fired at 900 °C and 1000 °C demonstrated the same final composition of Quartz, Anorthite, and Maghemite.

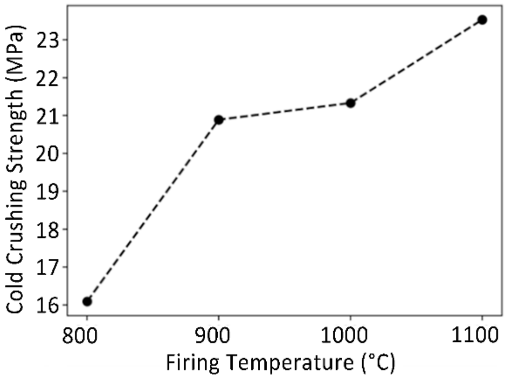

Fig. 8 Cold crushing strength values at increasing firing temperature

The formation of Maghemite occurred at all temperatures except at the firing temperature of 800 °C. While the other initial components underwent phase transformations, it can be said that Quartz underwent a transformation from α-quartz to β-quartz since this occurs at around 573 °C [27].

Unlike other studies, Quartz did not transform into cristobalite, which has more suitable refractory properties than the former[17-18]. The transformation of Quartz to Cristobalite usually occurs at temperatures between 1470 °C and 1730 °C [26]. As seen in Fig. 3, the bricks spalled, indicating structural instability at 1200 °C and at 1300 °C. Fired bricks completely melted, which placed a limit on the maximum firing temperature of the experiment. The presence of Quartz, Anorthite, and Maghemite contributed to the increasing and decreasing trend of the mechanical properties of the fired bricks.

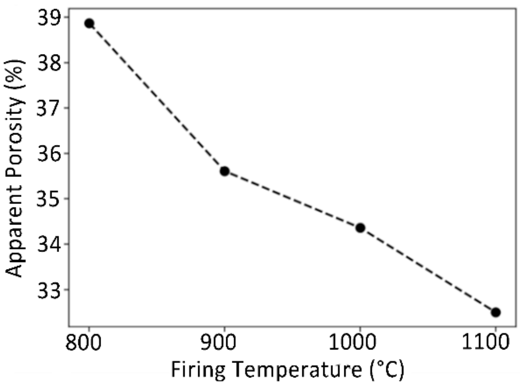

Fig. 10 Decreasing apparent porosity at increasing firing temperatures

Table 3 Mineralogical composition of fired green bricks at different firing temperature

Initial Composition	Firing Temperature(°C)	Final Composition
Quartz, Anorthite, Chlorite	800	Quartz, Anorthite
	900	Quartz, Anorthite, Maghemite
	1000	Quartz, Anorthite, Maghemite
	1100	Quartz, Anorthite, Maghemite

In Fig. 8, the cold crushing strength values increased as firing temperatures increased. The formation and presence of Anorthite and Maghemite are crucial in the trend as both exhibit strong, stable lattice structures, thereby improving the brick's mechanical strength, with Maghemite having high hardness and rigidity.

The increased strength could also be attributed to grain growth and neck formation as the crystalline lattices expand, making the brick more structurally cohesive, thereby improving the cold crushing strength values[25].

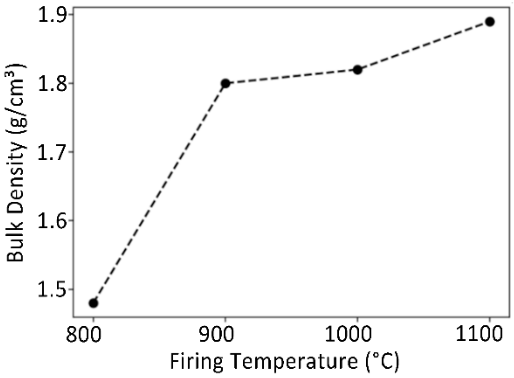

Fig. 9 Increasing bulk density values at increasing firing temperatures

At elevated temperatures such as 800 °C, pore closure results from a few phenomena occurring simultaneously. As the temperature is increased, Quartz partially melts, which fills in the vacant pores. This explains the decrease in apparent porosity in Fig. 9.

As more material occupies the pores, the fired brick becomes more compact. The volume occupied by the grains increased relative to the remaining voids, thus increasing bulk density as seen in Fig. 10.

From the aforementioned phenomena of decreasing apparent porosity and increasing bulk density, the volume shrinkage trend in Fig 11 increases as the material's microstructure becomes more compact with increasing temperature.

The values of bulk density and cold crushing strength were highest at the firing temperature of 1100 °C. At 1200 °C, the bricks exhibited signs of spalling and had a darker color than their lower temperature counterparts, and at 1300 °C, the fired bricks completely melted. Thus, the authors have decided that the point of comparison should be made on the properties of the fired brick at 1100 °C with other related studies. The cold crushing strength attained at 1100 °C was 23.53 MPa, which is significantly higher than the related studies [15-16]. The bricks produced by the cited studies only had cold crushing strength values of approximately 2.74 MPa and 1.2 MPa, respectively. This could well be attributed to the significant difference in bulk densities. The bricks fired at 1100 °C recorded a maximum bulk density of 1.82 g/cm³ compared to the 1.12 g/cm³ and 0.95 g/cm³ of similar studies[16], [14]. As bulk density increases, pores and voids get filled by additional material from the phase transformations that have occurred, thus improving mechanical strength[25]. According to ASTM, an insulating firebrick should have a bulk density not greater than 1.52 g/cm^3[28]. Looking at the results, a bulk density of 1.82 g/cm^3 exceeds the stipulation. Results from related studies producing insulation fire bricks have achieved the lightweight requirement by the addition of admixtures into their green brick formulations[2], [15-16].

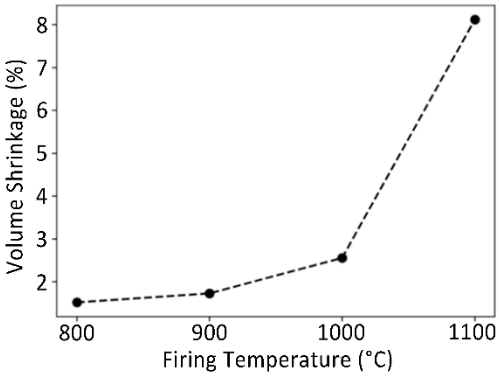

Fig. 11 Increasing volume shrinkage values at increasing firing temperatures

5. CONCLUSION

The study demonstrates that local quarry waste from Barangay Binaliw, Cebu City, Philippines, can be effectively transformed into insulating firebricks for thermal applications. Detailed chemical and mineralogical analysis confirmed the presence of Quartz, Anorthite, and Chlorite. Upon sintering between 800°C and 1100°C, the resulting firebricks showed a final composition of Quartz, Anorthite, and Maghemite, with promising mechanical and thermal properties. Specifically, the bulk density reached a maximum of 1.83 g/cm³, and the cold crushing strength was highest at 23.53 MPa when sintered at 1100°C. At a temperature of 1200 °C, signs of spalling and color darkening indicated thermal limitations, with complete melting observed at 1300°C. This suggests an optimal application limit below 1100°C for stable performance.

The firebricks exhibited increasing bulk density and cold crushing strength with rising temperatures, which corresponded to reduced apparent porosity and enhanced volume shrinkage due to phase transformations filling pore spaces. Compared to similar studies, the mechanical properties achieved in this study are superior, potentially due to the specific mineral transformations of Quartz to β-quartz and Anorthite formation at lower temperatures. While the bricks' density slightly exceeds ASTM standards for lightweight insulation materials, future studies incorporating porosity-inducing admixtures could optimize the bricks' insulation capacity to meet standard classifications.

The implications of this study extend beyond the production of insulating firebricks. By converting quarry waste, a major environmental pollutant, into a valuable industrial material, this research supports sustainable construction practices and aligns with the principles of a circular economy. Using quarry waste reduces the need for non-renewable materials like fireclay and kaolin, decreases landfill waste, and mitigates the environmental damage caused by quarrying activities. This successful transformation of waste into high-performance insulating firebricks demonstrates the potential for adopting similar methods in other regions with abundant quarry waste, providing a scalable and sustainable solution for innovative material development in the construction industry.

6. ACKNOWLEDGMENTS

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