EXTRACTION OF ALUMINA FROM FORMULA MILK PACKAGING WASTE FOR USE AS AN ALLOY MATERIAL IN FIRE-RESISTANT BRICK MANUFACTURING

(Ekstraksi Alumina dari Limbah Bungkusan Aluminium Sebagai Bahan Paduan Tanah Merah dalam Pembuatan Batu Bata Tahan Api (*Fire-Resistant Brick*))

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ABSTRAK: Pada penelitian ini, telah dilakukan pengujian tahap awal sifat tahan api batu bata yang dibuat dari tanah merah dan alumina (Al_2O_3) sebagai bahan paduannya. Bahan Al_2O_3 diperoleh dari ekstraksi limbah bungkusan susu formula, sedangkan tanah merah yang digunakan berasal dari daerah distrik Warmare, Manokwari Barat, Papua Barat. Analisis kandungan tanah merah menggunakan XRF diperoleh komponen utama berturut-turut 39.57%, SiO_2, 30,94% Al_2O_3 dan 23,73% Fe_2O_3. Proses ekstraksi dilakukan dengan metode gravimetri, melarutkan limbah alumunium dalam larutan HCl 18%, selanjutnya pengendapan $Al(OH)_3$ menggunakan larutan Amoniak 25%. Konversi endapan $Al(OH)_3$ menjadi Al_2O_3 dengan proses kalsinasi pada suhu 800 °C, hasil analisis XRF terhadap ekstrak yang diperoleh menunjukan 89.1% Al_2O_3, 3.95% SiO_2, 3.06% NA_2O dan 1.79% MgO. Batu bata dengan kandungan Al_2O_3 30% dan 50% menunjukan sifat tahan api setelah dibakar pada suhu 300 °C dan 500 °C karena batu bata tersebut tidak mengalami keretakan.

Kata kunci: *batu bata tahan api, ekstraksi, alumina, tanah merah.*

INTRODUCTION

The food and beverage industry is currently experiencing rapid development driven by technological advancements, lifestyle changes, and evolving innovations, leading to an increasing demand for raw materials. One of the most widely used raw materials in this industry is aluminum, which is commonly utilized for packaging (Widyabudiningsih D. & Widiastuti L., 2015). Aluminum is highly favored as a packaging material owing to its robust strength, lightweight nature, heat resistance, and near-complete impermeability to air, as well as its non-magnetic properties. The material's resistance to oxygen penetration renders aluminum foil an optimal choice for packaging applications. (Ariani N. M & Mahmudah L, 2017).

This material is discarded after a single use, contributing to the accumulation of non-organic waste that is challenging for soil decomposition and imposes environmental consequences. Researchers have proposed various methods to repurpose aluminum waste into valuable resources. For instance, it can serve as a raw material for coagulants in mineral acid water treatment (Busyairi *et al.*, 2018) and be utilized in the production of hydrogen gas with NaOH catalysts (Hakim & Marsalin, 2017). Furthermore, efforts have been made to mitigate aluminum waste by employing it in the manufacturing of handicrafts or vehicle accessories (Santoso E. B. & Syaichu A. 2020).

Aluminum found in food and beverage packaging waste can be recycled into alumina (Al_2O_3), a valuable material known for its high melting point, corrosion resistance, and strength (Johan A., 2009). Alumina has been utilized as an alloy in the production of refractory fire-resistant bricks (Sari A. L. & Rusiyanto. 2019). Refractory materials are composed of inorganic, non-metallic solid substances capable of withstanding chemical compounds, high temperatures, and mechanical stress (Gunawan *et al*., 2022). Firebricks, a common type of refractory material, often consist of silica, magnesite, zirconia, alumina and other fire-resistant materials, which are crucial for industries operating high-temperature processes.

Research indicates that the aluminum content in used cans is approximately 16.04% (Febrina L. & Zilda A., 2019), and it has been utilized as a coagulant. Furthermore, used cans can be sold to collectors for recycling, thereby addressing significant environmental concerns. Similarly, due to its aluminum content, formula milk packaging waste has the potential to be converted into alumina. Given this potential, there is a need for research on the conversion of formula milk packaging waste into alumina, which can serve as an alloy material in the construction of fire bricks. Recycling or transforming aluminum waste into valuable commodities can contribute to reducing environmental impact and generating economically valuable products.

EXPERIMENTAL

Raw Material Preparation

The aluminum waste utilized in the experiment comprised milk packaging collected from households. Meanwhile, the red soil was sourced from the Warmare district in West Manokwari, West Papua. Both materials underwent cleaning and drying under direct sunlight. The aluminum waste was cut into 1x1 cm pieces and stored in a sealed container, while the red soil was granulated to a 100-mess size. The chemical composition of the red soil sample was analyzed using the X-ray fluorescence (XRF) method, conducted at BRIN Serpong in South Tangerang.

Extraction of Alumina

A 50-gram sample of the aluminum waste was immersed in 500 mL of an 18% HCl solution. The mixture was heated to 80 °C on a hotplate until complete dissolution of the aluminum occurred, leaving behind plastic residues. After cooling, the solution was filtered to separate the residues. Subsequently, 250 mL of a 25% NH_4OH solution was added to precipitate the alumina. The resulting solution was filtered, and the precipitate was dried at 100 °C for 24 hours before undergoing calcination at 800 °C for 3 hours. The alumina was then characterized using the X-ray diffraction (XRD) and X-ray fluorescence (XRF) methods. The XRF analysis was conducted at the BRIN Serpong in South Tangerang, while the XRD characterization was performed at the UGM campus in Yogyakarta.

Manufacture of Firebrick Refractory

The firebrick material was composed of alumina and red soil, with alumina weight percentages of 0%, 30%, and 50%. 75 mL of aquades were added to form a dough of pulverized flour, and the firebricks were then molded using press tools into dimensions of 5x5x5 cm. After the manufacturing process, the bricks were sun-dried for a week. Fire resistance testing was conducted by heating the bricks at 100 °C, 300 °C, and 500 °C for 3 hours (with a heating rate of 2 °C/min, a holding time of 30 minutes, and a cooling rate of 10 °C/min).

RESULTS AND DISCUSSION

The Composition of Red Soil and Alumina Extract

Red soil is a type of soft clay formed by the weathering of iron-containing rocks, which gives the soil its characteristic red color. The most common minerals found in red soil include sand (quartz), clay (kaolinite), and metal oxides (such as aluminum oxide). It has been reported that two types of iron oxides commonly found in red soils are Goethite (FeO(OH)) and Hematite (Fe_2O_3). Soils with a hue ranging from 10R to 5YR are typically composed of Hematite, while soils with a hue between 2.5YR and 7.5YR predominantly contain Goethite (Eswaran and Sys, 1970). Therefore, the color of red soils serves as a crucial parameter for determining their composition (Mulyanto D., 2020). Red soil exhibits excellent thermal resistance and can be utilized as a refractory material or fire-resistant brick due to the presence of aluminum in the soil. Aluminum exists as aluminum oxide or alumina (Al_2O_3) in red soils. This compound possesses hardness and strength, enabling it to effectively resist vibrations. Alumina also exhibits excellent resistance to high temperatures and functions as an electrical insulator, which is why it is commonly used as an alloying material in the production of refractory materials. Analysis of the red soil composition from the Warmare district, West Manokwari, revealed the presence of 39.57% SiO_2, 30.94% Al_2O_3, and 23.73% Fe_2O_3. The percentage of aluminum required for usage as a refractory material ranges from 25.4% to 41.9% (Charles A.S., 2004). Based on the analysis results of the components (Figure 1), the data indicate that the aluminum percentage in the soil sample is 30.94%, suggesting that the soil is suitable for the manufacture of fire-resistant bricks. However, to achieve optimum fire resistance, the concentration of aluminum in the soil must be increased.

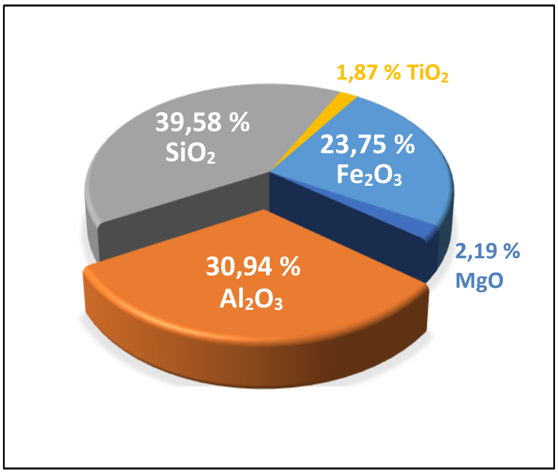

Figure 1. The percentage composition of compounds in the red soil sample.

The XRF analysis of the alumina extract (Figure 2) revealed that the Al2O3 compound was the predominant component, constituting 89.09%, indicating that the extraction process was successfully carried out.

The reaction of aluminum and acid: (Widyabudiningsih dan Widiastuti, 2015)

$$2Al_{(s)} + 6H_3O^+_{(aq)} \rightarrow 2Al^{3+}_{(aq)} + 6H_2O_{(l)} + 3H_{2(g)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

The reaction of aluminum and base: (Widyabudiningsih dan Widiastuti, 2015)

$$2Al^{3+}_{(aq)} + 2OH^-_{(aq)} + 6H_20_{(l)} \rightarrow 2[Al(OH)_4]^-_{(aq)} + 3H_{2(g)} \quad \ldots\ldots\ldots\ldots\ldots\ 2$$

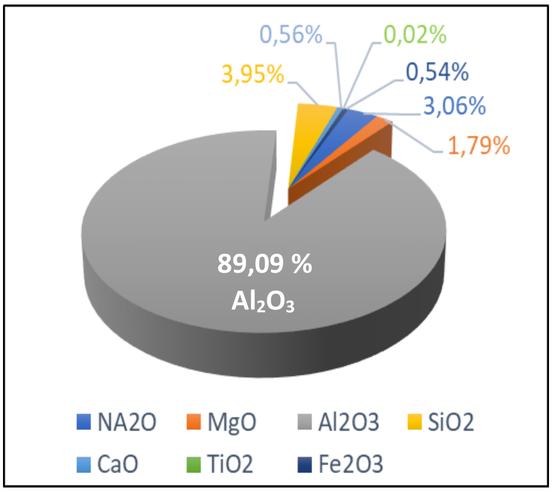

Figure 2. The percentage composition of compounds in the alumina extract.

The XRD analysis revealed a composite of aluminum phases (γ-Al_2O_3, δ-Al_2O_3, and θ-Al_2O_3) in the extract, with diffractogram peaks at (2θ) 37.4°, 45.6°, and 67.1° (Figure 3). Determining the type of alumina formed is crucial, as its characteristics are significantly influenced by its phase structure. The peak results obtained from the diffractogram align with previous findings reported by Souza *et al.* (2015) and Ayu *et al.* (2020). These studies indicate that typical peaks of γ-Al_2O_3 and δ-Al_2O_3 occur at angles (2θ) of 37.4° and 45.6°, respectively, while θ-Al_2O_3 is observed at an angle (2θ) of 67.1°.

Alumina exists in several phases, including the stable form α-Al_2O_3 and various metastable alumina phases such as gamma alumina (γ-Al_2O_3), delta alumina (δ-Al_2O_3), theta alumina (θ-Al_2O_3), kappa alumina (κ-Al_2O_3), and chi alumina (χ-Al_2O_3). Gamma alumina (γ-Al_2O_3) is a highly significant material in the industrial sector, being used as a catalyst substrate in automotive and petroleum industries, as a structural component in aerospace applications, and as protective clothing against friction, heat, abrasion, and thermal stress (Paglia et al., 2004)

The transition phases of alumina begin with the conversion of $Al(OH)_3$ (gibbsite) to $AlO(OH)$ (boehmite) at around 300 °C. Subsequently, the transition from boehmite to the γ-Al_2O_3 phase occurs at 500 °C. The δ-Al_2O_3 phase forms at 800 °C, followed by the θ-Al_2O_3 phase at 1000 °C. Additionally, the transformation phase from θ-Al_2O_3 to α-Al_2O_3 occurs at temperatures above 1000 °C. α-Al_2O_3 is the most stable phase, exhibiting high thermal conductivity and chemical stability.

Alumina phase transformations:
(Ayu *et al*, 2020)

$$Al(OH)_3 \rightarrow AlO(OH) \rightarrow \gamma\text{-}Al_2O_3 \rightarrow \delta\text{-}Al_2O_3 \rightarrow \theta\text{-}Al_2O_3 \rightarrow \alpha\text{-}Al_2O_3 \quad \ldots\ldots\ldots 3$$

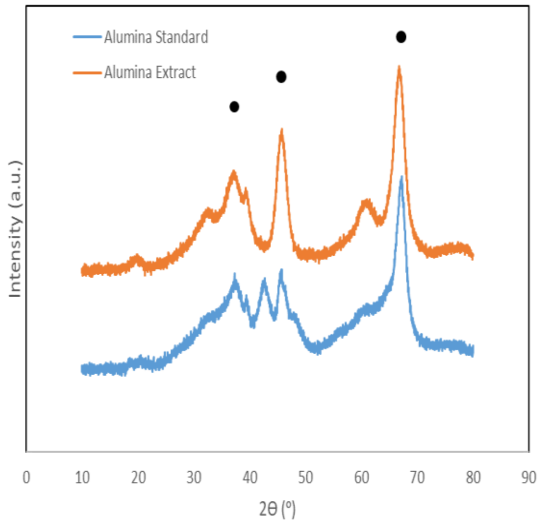

Figure 3. X-ray diffraction patterns for alumina sample.

Result of Bricks Burning

According to Eryunaningsih (2024), the addition of specific materials to soil enhances its properties, enabling it to meet technical requirements such as bearing capacity and strength, thereby making it suitable for building or infrastructure construction. This constitutes a chemical soil stabilization method. Thus, the incorporation of alumina into red soil constitutes a strategic approach to enhancing soil quality, thereby ensuring its suitability for building construction.

Fire-resistance testing of dried bricks was conducted by burning them in a furnace for 3 hours at temperature variations of 100 °C, 300 °C, and 500 °C. The results revealed no cracks in bricks with a concentration ratio of 0% at 100 °C. However, at 300 °C, slight cracks were observed, and at 500 °C, significant cracking occurred (Figure 4). Bricks with 30% (Figure 5) and 50% (Figure 6) alumina concentrations showed no cracks at 300 °C and 500 °C, regardless of whether alumina extract or standard alumina (P) was used. This indicates that bricks with higher amounts of alumina are more resistant to high temperatures. In addition to its exceptional thermal resistance, an excess of alumina promotes the formation of dense and robust bonds with silica, culminating in the development of aluminosilicate materials. Consequently, this process significantly reduces brick porosity. In other words, alumina effectively seals the pores, which inherently represent the weakest points in brick structures.

These results represent an initial test of the fire-resistance properties of bricks made from red clay and alumina extracted from formula milk packaging waste. Further testing is required to determine the maximum temperature these bricks can withstand.

CONCLUSION

Based on the results, it can be concluded that alumina was successfully extracted from formula milk packaging waste, yielding an alumina composition of 89% according to the XRF analysis. Additionally, the X-ray diffractogram (XRD) pattern indicated that the alumina phases obtained were composites of γ-Al_2O_3, δ-Al_2O_3, and θ-Al_2O_3, with peaks at angles (2θ) of 37.4°, 45.6°, and 67.1°, respectively. Furthermore, the results of burning at 300 °C and 500 °C revealed cracks in brick samples with 0% aluminum concentration, while bricks with concentrations of 30% and 50% alumina showed no cracks. This indicates that the fire-resistant properties of bricks increase as the amount of aluminum in the soil increases.

This study also concludes that aluminum packaging waste from formula milk has the potential to be utilized for producing useful and economically valuable commodities. Moreover, the utilization of such waste can reduce environmental impact.

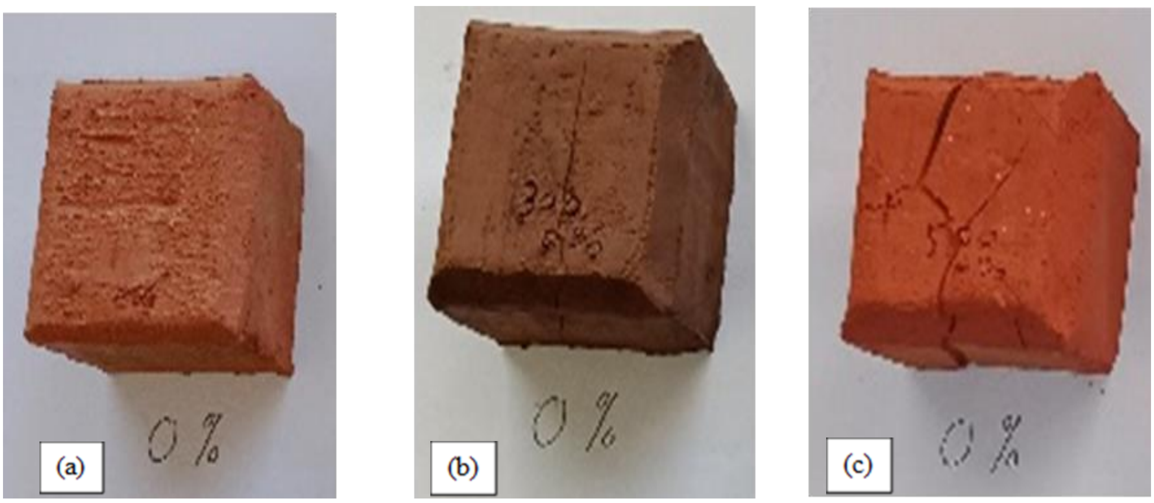

Figure 4. Results of bricks burning with 0% concentration alumina at temperatures (a) 100°C, (b) 300°C, and (c) 500°C.

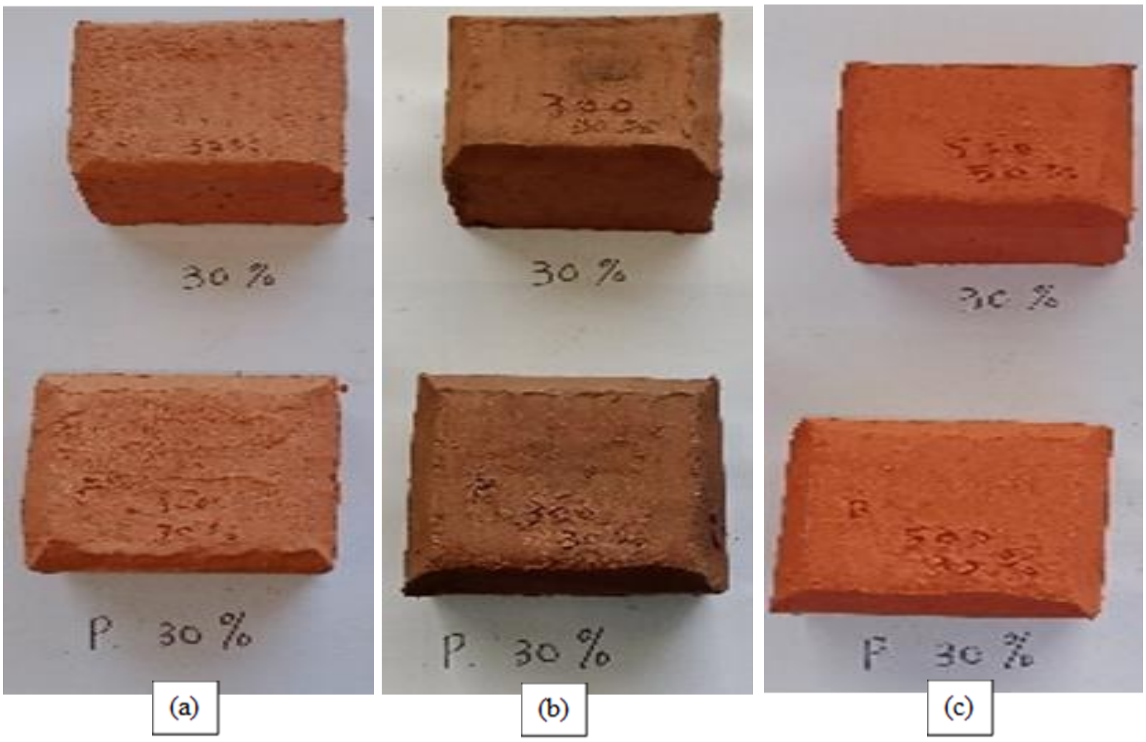

Figure 5. Results of bricks burning with 30% concentration alumina at temperatures (a) 100°C, (b) 300°C, and (c) 500°C.

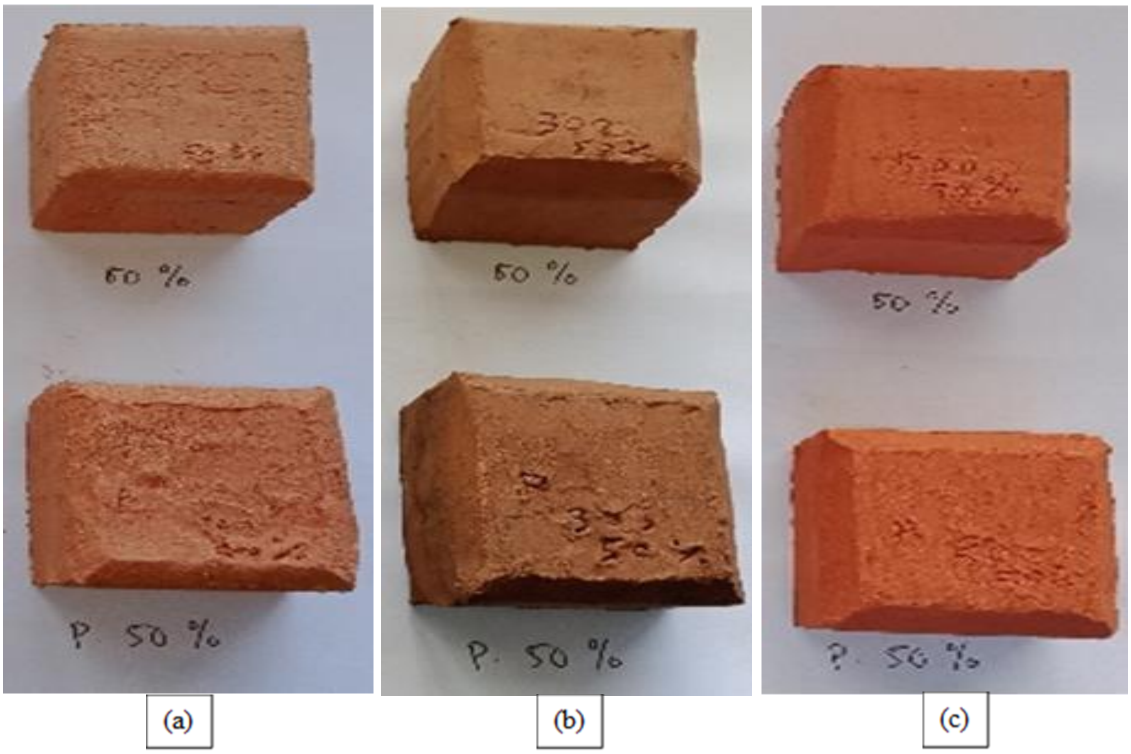

Figure 6. Results of bricks burning with 50% concentration alumina at temperatures (a) 100°C, (b) 300°C, and (c) 500°C.

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