Incorporation of gold and limestone mining waste materials for carbon capture and storage in bricks

S N M S Hasan¹, F M Kusin¹,², M A Hassim¹ and V L M Molahid¹

¹Department of Environmental Sciences, Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
²Environmental Forensics Research Unit (ENFORCE), Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Corresponding author: faradiella@upm.edu.my

Abstract. The industrial sector is the main contributor of carbon dioxide emissions which have an enormous impact on the planet’s weather. One of the approaches to sequester carbon dioxide permanently is through the utilization of potential mining waste to produce commercial materials such as bricks. This research emphasizes the use of gold and limestone mining waste as raw materials for carbon capture and storage in the manufacturing of bricks and to determine their physical and mechanical characteristics for construction purposes. The dimensions of the sand bricks in this research were 215×103×65 mm. Gold and limestone mining waste was used as a partial cement replacement in sand bricks. Findings showed that the gold mine waste bricks have an average of 1.8% higher water absorption value and hence are more permeable, compared to the average of 1.05% in limestone mine waste bricks. Compressive strength measurements indicated that bricks made up of limestone mine waste have an average of 34.72 N/mm², which is greater than the average of 24.09 N/mm² for gold mine waste bricks. Limestone mine waste bricks exhibit good durability of the bricks as compared to gold mine waste bricks, because of their low water absorption. Thus, they have greater strength for construction purposes. Limestone mine waste bricks are more appropriate for buildings because they are less permeable and have greater brick power than gold mine waste bricks. Thus, utilization of mining waste as a raw material for bricks production might increase the physical and mechanical properties of bricks and provide potential solutions for permanent carbon dioxide storage.

1. Introduction

Since the industrial revolution, global warming has continuously intensified as a result of an increase in greenhouse gas (GHG) emissions, especially carbon dioxide (CO₂). Human activities forcing fluxes involving combustion of fossil fuels, industrial processes and land use changes have resulted in increased CO₂ emissions in the atmosphere over the past two and a half centuries [1]. The current atmospheric CO₂ concentration has been recorded to have increased as much as 28% from 280 ppm in 1750’s to 389 ppm in 2010 [2]. As global energy use and supply is expected to grow, especially as developing countries are pursuing industrialization, it is expected that fossil fuels will maintain their dominance till 2030 and beyond. If no proactive mitigation measures are taken, CO₂ emissions are likely to increase by 40% in 2030 compared to 23.5 Gt of CO₂ per year in 2000 [3].

Meanwhile, mining activities adversely cause environmental degradation, contamination of soil and water and also of biodiversity [4]. Waste produced from metallic mining is often stored in piles nearby
mining sites. These piles are also called ‘tailings’. However, such waste is not normally restored or properly regulated. As a result, soil erosion and toxic element leaching tend to occur in the uncovered areas. Moreover, the affected area is also not suitable for living organisms due to high metal concentrations, high acidity or alkalinity, high salt concentrations, low organic matter and nutrient content and low water retention capacity [5].

The two problems above can be solved if mining waste is utilized as a raw substance to make bricks. This can also help in capturing carbon dioxide permanently. Carbon capture and storage (CCS), also known as carbon sequestration through mineral carbonation, is an environmentally sound approach to permanently storing CO₂ in the form of stable carbonates [6-8]. In this research, mining waste materials are used because they are the potential feedstock for carbon sequestration due to the presence of divalent cations such as calcium (Ca), magnesium (Mg) and iron (Fe); and silicate minerals which can undergo carbon fixation in the presence of carbon dioxide to form carbonate compounds [9-11]. Rocks and minerals act as a passive agent in which CO₂ sequestration reduces CO₂ emissions, enabling long-term CO₂ removal from the atmosphere [12,13]. Mining waste bricks are produced as permanent carbon dioxide storage products, where the production is dependent on the composition of mining waste used as a raw substance in bricks. Furthermore, the potential use of mining waste can reduce the cost of brick production due to high silica and calcium oxide contents in gold and limestone mining waste respectively [12,14,15]. Thus, utilization of mining waste can improve the physical and mechanical properties of bricks.

Many studies have explored the use of industrial by-products or waste products such as fly ash [16,17], cockle shells, palm oil fuel ash (POFA) [18], powder lime and brick dust [19,20] as a partial cement replacement in brick production. However, there has not been much research conducted on the potential use of mining waste for carbon capture and storage in bricks. Therefore, the current study is conducted to emphasize on the utilization of mining waste materials, specifically, gold and limestone, as raw substances for carbon capture and storage in bricks, and to evaluate their physical and mechanical properties for construction purposes.

2. Material and Methods

2.1. Composition of Mining Waste Sample

In this study, gold mine waste was collected at Selinsing gold mine in Pahang, Malaysia, while limestone mine waste was obtained from limestone quarry in Kinta Valley, Perak. The chemical compositions of gold and limestone mine waste were quantified using energy dispersive X-ray (EDX) (Table 1). Mining waste was used because it consists of silicate waste rocks that are rich in divalent cations such as calcium (Ca), magnesium (Mg) and iron (Fe) silicate minerals, which can facilitate the production of carbonate when reacting with CO₂ [7-9]. Additionally, a previous study has revealed the potential of the gold mine waste at Selinsing for passive carbon sequestration due to the presence of Mg- and Fe-silicate minerals that are favourable for mineral carbonation [12]. High calcium content in limestone also makes it a good potential candidate for carbon sequestration. Therefore, utilization of mining waste that is rich in Mg-Ca-Fe, as raw materials for bricks production can help to sequester and store CO₂ permanently.

| Table 1. The chemical composition of gold and limestone mine waste |
|---------------------------------------------------------------|
| **Compound (%)** | **Mining Waste** |
|                  | Gold (Rock) | Gold (Sludge) | Limestone (Rock) |
| MgO*             | 1.14*       | 2.72*         | 1.74*            | n.d. |
| SiO₂             | 22.92       | 48.46         | 60.39            | 1.02 |
| CaO*             | 55.12*      | n.d.          | n.d.             | 82.88* |
| Fe₂O₃*           | n.d.        | 11.79*        | 3.20*            | n.d. |
| Al₂O₃            | 2.60        | 20.18         | 18.22            | n.d. |
2.2. Preparation of Bricks
A total of seven units of sand bricks were prepared with dimensions of 215×103×65 mm based on Malaysian Standard, MS 7.6: 1972 [21]. The mixtures contained cement ranging from 30% to 60% and sand from 10% to 40%, in addition to gold and limestone mine waste ranging from 30% to 60% as partial cement replacement in bricks. Mould made of plywood was used to shape the bricks. Cement and sand were obtained from a local supplier. Tap water was used in the process of brick mixing. After that, the bricks were air-dried for about 14 days (2 weeks) to ensure that the bricks were dry completely. Then, the physical and mechanical properties of bricks such as water absorption and compressive strength were analyzed.

2.3. Water Absorption Test
All of the bricks were weighed respectively to find initial mass. They were ventilated in an oven at 105°C to constant mass within 24 hours, accepting only 0.2% mass loss. The bricks were allowed to cool for at least four hours at room temperature. The bricks were subsequently immersed into water with temperature of 20°C ± 5°C at a depth of 5 mm ± 1 mm according to Malaysian Standard, MS 1933: Part 11:2007 [22]. The bricks were immersed completely for 24 hours. The bricks were then removed, the surface was wiped off after the time of immersion, and they were weighed one by one. The percentage of water absorption was calculated based on British Standard, BS 3921:1985 [23]:

\[
\text{Percentage by weight (\%) = } \left( \frac{M_2 - M_1}{M_1} \right) \times 100
\]

\(M_1\) is mass of the bricks after drying (g) and \(M_2\) is the mass of the bricks immersed in water (g).

2.4. Compressive Strength
Compressive strength testing was conducted based on Malaysian Standard MS 1933 Part 1: 2007 [24]. The steel surfaces of the testing machine were cleaned and loose particles on the surface of the bricks were removed. Then, the bricks were placed into the universal testing machine (UTS 50000 kN). Brick samples were tested between two plywood sheets, each 3 mm thick, which were placed at the bottom and top of the bricks respectively, before the load was applied. Then, the maximum failing load was recorded when no further increase was observed in the indicator reading. The compressive strength of bricks was calculated by dividing the maximum failing load (N) with the brick surface area (length x width) in mm², which was then expressed in N/mm² as shown in the following equation [24,25]:

\[
\text{Compressive strength (N/mm}^2\) = \frac{\text{Maximum load fails (N)}}{\text{Brick surface area (mm}^2\})
\]

3. Results and Discussion

3.1. Water Absorption
In general, the percentage of water absorption for gold and limestone mine waste bricks is between 0.52% to 2.24%, which is below the maximum percentage required by Malaysian Standard, MS 1972 (Class A: 4.5%, Class B: 7%) [23] and British Standard, BS 8007:1987 (≤ 3%) [26] (Figure 1). Among all bricks, gold mine waste brick has a higher value of water absorption averaging 1.8%, followed by control brick which is at 1.31%. On the other hand, limestone mine waste brick has a lower water absorption value averaging at 1.05%, compared to a control brick. Water absorption is associated with the microstructure of materials and hence depends on the open pores volume fraction [27-29]. Findings indicated that gold mine waste brick is more permeable compared to limestone mine.
waste brick and control brick. This is due to the high content of silica which is present in gold mine waste, which may increase the volume fraction in the brick [30]. Although limestone mine waste brick is less permeable, the low porosity of limestone mine waste indicates that it has better properties of the sand bricks for construction purposes.

Figure 1. Variation in water absorption in seven types of bricks according to MS 1972 and BS 8007

3.2. Compressive Strength
The compressive strength for gold and limestone mine waste bricks is between 19.49 N/mm² to 40.23 N/mm², which is above the minimum value required by the American Society for Testing and Materials, ASTM C55-11 (17.2 MPa) [31] (Figure 2). Most of the strength of the brick including normal brick, 60% of gold, 40% and 50% of limestone mine waste was classified as Class 4 (minimum 27.5 N/mm²) for load bearing brick according to Malaysian Standard, MS 7.6: 1972; while 60% of limestone mine waste brick was classified as Class 5 (minimum 34.5 N/mm²) [21]. Both 40% and 50% of gold mine waste bricks were classified as Class 2 (minimum 14.0 N/mm²) and Class 3 (minimum 20.5 N/mm²), respectively. Findings indicated that the higher the percentage of mining waste, the higher the compressive strength. Results show that limestone mine waste bricks have a higher compressive strength averaging at 34.72 N/mm², as compared to control bricks. Since gold mine waste has high porosity, this will reduce the strength of the brick [33]. In terms of carbon sequestration, carbonation of reactive components such as CaO and MgO in gold and limestone mine waste will produce carbonate minerals which act as additional binders, thus increasing the strength of the bricks [34]. One of the most important considerations for use in concrete structure is compressive strength. The present of limestone mine waste improves the strength of bricks further as compared to bricks containing gold mine waste. Therefore, brick containing limestone mine waste are considered good quality bricks and are suitable for construction purposes.
Figure 2. Compressive strength in seven types of bricks according to MS 7.6: 1972/BS 3921: 1985 and American Society for Testing and Materials, ASTM C55-11

4. Conclusion
This study has discovered that the incorporation of mining waste materials such as gold and limestone mining waste for carbon sequestration, increase the permeability and strength of sand bricks. Utilization of gold and limestone mine waste as supplementary materials for brick production can improve their physical and mechanical properties for use in construction industry. Higher amounts of silica and calcium content in gold and limestone mine waste, can enhance the properties of materials in bricks, and also provide potential divalent cations for permanent carbon storage. In comparing the properties of bricks using gold and limestone mine waste as raw substances, it seems that the gold mine waste bricks exhibited lower water absorption, while the limestone mine waste increased the strength of the brick, making them suitable for construction purposes. Overall, it can be inferred that the integration of mining waste into the production of sand bricks would contribute towards an environmental and economically sound approach in providing potential solutions for mitigating CO₂ emissions in the long run.

Acknowledgments
This research was supported by Ministry of Higher Education Malaysia, vote number FRGS 5524757 and 5540081; and Universiti Putra Malaysia, vote number IPS 9574900. Authors wishing to acknowledge laboratory staffs at Faculty of Environmental Studies and Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia for their technical assistance.

References
[1] Raupach M R, Marland G, Ciais P, Le Quéré C, Canadell J G, Klepper G and Field C B 2007 Proc. Natl. Acad. Sci. U S A 104 10288–293
[2] Bernstein L., et al. 2007 Climate Change 2007: Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (United Kingdom and New York: Cambridge University Press) p 496
[3] Metz B, Davidson O R, Bosch P R, Dave R and Meyer L A 2007 Climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press: United Kingdom and New York)
[4] Luptakova A, Ubaldini S, Macingova E, Fornari P and Giuliano V 2012 Process Biochem. 47 1633–39
[5] Lottermoser B G 2010 Mine Wastes: Characterization, Treatment and Environmental Impacts (London: Springer) p 400
[6] Arce G L A F, Neto T G S, Ávila I, Luna C M R, dos Santos J C and Carvalho J A 2017 Hydrometallurgy 169 142–51
[7] Lackner K S, Wendt C H, Butt D P, Joyce E L and Sharps D H. 1995 Energy 20 1153–70
[8] Renforth P, Washbourne C L, Taylder J, Manning D A C 2011 Environ. Sci. Technol. 45 2035–41
[9] Pan S-Y, Chang E E, and Chiang P-C 2012 Aerosol Air Qual. Res. 12 770–91
[10] Power I M, Harrison A L and Dipple G M 2013 Rev. Mineral. Geochem. 77 305–60
[11] Li P, Pan S-Y, Pei S, Lin Y J and Chiang P-C. 2016 Aerosol Air Qual. Res. 16 1327–44
[12] Hasan S N M S, Kusin F M, Shamshuddin J and Yusuff F M 2018 Minerals 8 257
[13] Hasan S N M S and Kusin F M 2018 IOP Conf. Ser. Mater. Sci. Eng. 458 012013
[14] Renforth P, Washbourne C L, Taylder J and Manning D A C. 2011 Environ. Sci. Technol. 45 2035–2041
[15] Assima G P, Larachi F, Molson J and Beaudoin G 2014 Chem. Eng. J. 240 394–403
[16] Shakir A A, Naganathan S and Mustapha K N 2013 Constr. Build. Mater. 41 131–138
[17] Rahman M E, Ong P J, Nabilejad O, Islam S, Khandoker N A N, Pakrashi V and Shorowordi K M 2018 Technolog ies 6 20
[18] Mat-Aris S, Muthusamy K, Uzer A and Wan-Ahmad S 2018 IOP Conf. Ser. Earth Environ. Sci. 140 012015
[19] Khan M N A, Liaqat N, Ahmed I, Abdul-Basit, Umar M and Khan M A 2018 IOP Conf. Ser. Mater. Sci. Eng. 414 012005
[20] Basit A, Khan M A, Ahmed I, Khan M N A and Umar M 2018 IOP Conf. Ser. Mater. Sci. Eng. 414 012008
[21] MS 76. 1972 Specification for Bricks and Blocks of Fired Brickearth, Clay or Shale. Part 2: Metric Unit. Selangor
[22] MS 1933: Part 11:2007 Methods of Test for Masonry Unit. Part 11: Determination of Water Absorption of Aggregate Concrete, Manufactured Stone and Natural Stone Masonry Units Due to Capillary Action and the Initial Rate of Water Absorption of Clay Masonry Units. Selangor
[23] BS 3921. 1985 Specification for Clay Bricks. London
[24] MS 1933: Part 1. 2007 Methods of Test for Masonry Units. Part 1: Determination of Compressive Strength Selangor. London
[25] Fernando P R 2017 Journal of Energy and Natural Resources J Energy Nat. Resour. 6(5) 58-63
[26] BS 8007. 1987 Code of Practice for Design of Concrete Structures for Retaining Aqueous Liquids. London
[27] Azmi N B, Khalid F S, Irwan J M, Mazenan P N, Zahir, Z and Shahidan, S 2017 IOP Conf. Ser. Earth Environ. Sci. 140 012129
[28] Zhang S P, and Zong L 2014 Adv. Mater Sci Eng. p 8
[29] Jiménez-Quero1 V, Maza-Ignacio, O T, Guerrero-Paz J and Campos-Venegas K 2017 IOP Conf. Ser. Journal of Physics 792 012065
[30] Runze C, Mandula and Jinyi, C 2018 IOP Conf. Ser. Earth Environ. Sci. 113 012136
[31] ASTM C55-11:2011 Standard Specification for Concrete Building Brick. West Conshohocken
[32] Önel O, Tanriverdi M and Cicek T 2017 IOP Conf. Ser. Earth Environ. Sci. 95 042012
[33] Wong C L, Mo K H, Yap S P, Alengaram U J and Tung-Chai L 2018 J Clean. Prod. 195 226–39
[34] Power I M, Dipple G M, Francis P S 2017 Cement Concrete Com. 78 97–107