Alkaline solidification of gold mine tailings for production of lightweight masonry blocks

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Abstract. South Africa is the world's largest gold resource. This is due to the substantial amount of gold that exists in the Witwatersrand Basin. The processing of gold leads to the production of gold mine tailings. Gold mine tailings are generated from mineral processing of gold ore through which gold is separated. Mine tailings are generally waste materials and are normally disposed of in slurry form in storages constructed on huge areas of land, these storage facilities are called tailings dams. This study was conducted to strengthen and stabilize gold mine tailings by alkaline activation to produce masonry blocks that can be used for building and construction as per minimum requirements for ASTM C34-13, C129-14a and South African standard (SANS227: 2007). The effect of variation of Solid to liquid (S/L) ratio, NaOH concentration and temperature on the UCS was investigated. This was achieved by treating the gold mine tailings with NaOH solution. The feasibility of using gold mine tailings to produce lightweight masonry blocks was studied by conducting unconfined Unconfined Compressive Strength (UCS) tests, SEM imaging, and XRF and XRF analysis. The alkaline activation of Gold Mine Tailings (AU MT) at a S/L ratio of 14.31% and 9 M concentration had higher UCS than those produced at 3 M and 6 M. Curing temperature is an important factor affecting alkaline activation and the UCS of masonry block. The UCS increases with the curing temperature up to a certain level and then decreases with the curing temperature. For the AU MT herein, the optimum curing temperature was found to be 80 °C with bulk density of 1578 kg/m3. The AU MT based masonry block meet ASTM standards they can be used for building and construction purposes such as the building of structural clay load bearing wall tiles of all C34-03 ASTM designation grades and building blocks of ASTM designation C6210, type NW (negligible weathering) with the minimum UCS of 10.3 MPa.

1. Introduction

The mining of gold in South Africa continuously results in massive volumes of waste material, primarily in the form of tailings material [1]. Gold mine tailings are generated from mineral processing of gold ore through which gold is separated. Mine tailings are generally waste materials and are normally disposed of in slurry form in storages constructed on huge areas of land, these storage facilities are called tailings dams. The continuous storage of gold mine tailings in dams has foremost disadvantages that include failure of the storage dam, release of heavy metals due to acid mine drainage (AMD), surface erosion, costly construction, high maintenance and dust generation [2]. Gold mine tailings contain process water, gangue minerals, heavy metals and any harmful substances used in the beneficiation of ores. They are generally discarded into tailings dams in slurry shape with everything they contain. A Mintek database states that there are in excess 446 gold tailings dumps that extend to over 18 000 hectares crosswise over Johannesburg alone [3]. There are over 32 gold mines in the country, each generating their own fair share of waste mine tailings storing them in dams. The disposal of mine tailings is a liability as the mining activities are expanding and becoming bigger [4]. Mine tailings can cause water contamination, emerging from the release of water polluted with solids, heavy metals, process reagents, sulphur compounds, and so forth. Furthermore, failure of steep-sided tailing dams can occur because of seismic tremors, blasting vibration and extreme climate [4]. Previous research on alkaline activation of waste material to produce a building and construction material mostly focused most on using metakaolin, fly ash, and slag as the raw material for production of building material. Limited research has been reported on alkaline activation of AU MT for potential use in building and construction. Due to the high content of silica and alumina of Au MT, this study focuses on utilizing AU MT as the potential raw material to produce a building and construction material after alkaline activation. The very few researchers that investigated possible applications of beneficiation of the aforementioned waste materials in building and construction are; Kiventerä et al. [5] investigated the utilization of sulphidic gold mine tailings as a raw material in geopolymerization using NaOH as the alkaline activator. The results show that the it is possible to alkaline activate sulphidic mine tailings using 5 M NaOH without any co-binders, to produce building material with compressive strength up to 3.5 MPa. However, the downside is that water permeability is high indicating that the matrix is weak. Due to the chemical characteristics and geotechnical properties, most of the gold mine tailings require modification before the material can be used for any application. Zhang et al. [6] studied the synthesis of Fly Ash modified gold mine tailing geopolymers using NaOH as a alkaline activator. The results revealed that the compressive strength of the MT-based geopolymer can be controlled by adjusting the FA content and NaOH concentration. The MT-based geopolymers synthesized by varying these factors show UCS ranging from 1.37 to 21.2 MPa. So, the MT-based geopolymers are a viable and promising construction material which can be tailored for different applications. Rachman et al. [7] investigated the development of Portland cement modified traditional gold mine tailings based solidification. The result demonstrated that, the optimum ratio to mix Portland cement and tailings was 10:90, with compression test of 257ton/m2 and Toxicity Characteristic Leaching Procedure (TCLP) test was 0.0069 mg/L. The compression test results were in accordance to US EPA Standard quality of 35 ton/m2. Based on these studies the feasibility to alkaline activate Western basin mine tailings (South Africa) was explored. Alkaline activation was employed as a technology to stabilize and solidify gold mine tailings to use them as a dominant if not the only material for the production of masonry blocks.

2. Materials and Methods

Gold tailings samples were obtained from a Gold Mining company in the Western basin of South Africa. The The alkaline activator NaOH was supplied by Rochelle. X-ray Fluorescence (XRF-Rigaku ZSX Primus II) was used to determine the elemental composition of the material, X-ray Diffraction (XRD-Rigaku) to study the mineralogy of the material and Scanning Electron Microscope (SEM, Tescan Vega 3 XMU) for the morphology. The samples of gold tailings were dried in an oven at the temperature of 50 oC before conducting any experimental work. The material was then pulverized to fine particles size of -75µm. Alkaline activation of the gold mine tailings were carried out varying the NaOH concentrations, S/L ratio stirring and curing temperature. The developed specimens were cast and cured at different curing ages.

3. Results and Discussion

3.1. Effect of NaOH and S/L ratio on UCS

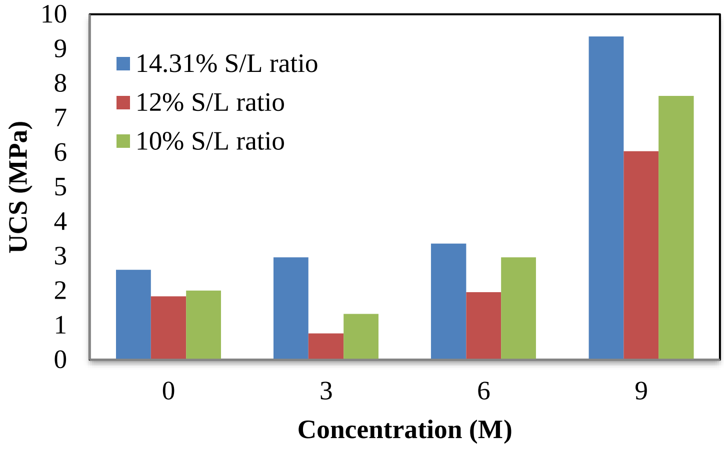

Figure 1. The effect of NaOH concentration and S/L on the UCS

Figure 1 shows the UCS of the masonry blocks after 7 days curing which shows that there was an increase in UCS with increase in NaOH concentration. The 9 M NaOH concentration gave the highest UCS; and was concluded to be the optimum concentration. This is due to more dissolution of aluminosilicates by using the 9 M NaOH solution. There was also an increase in UCS with an increase of water content. This was due to lower water content the paste was stiff reducing the time for dissolution of aluminosilicates and at higher water content the workability was high allowing more time for dissolution of aluminosilicate, which in turn enhances the UCS of the masonry block.

3.2. Effect of Temperature on UCS

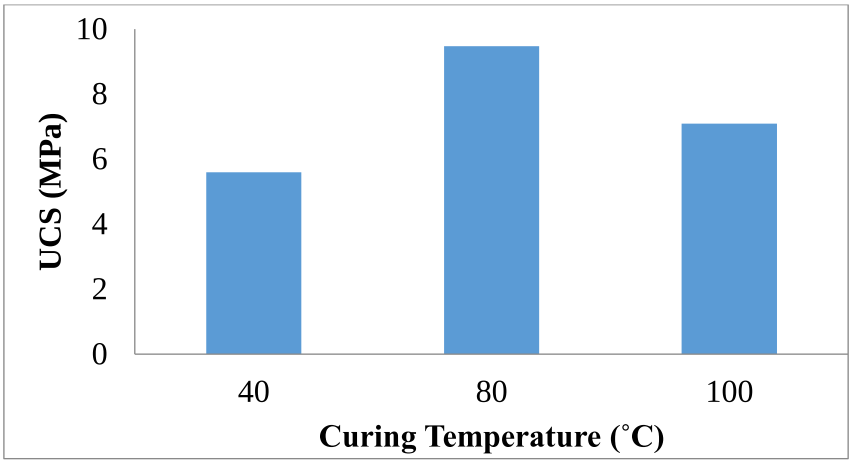

Figure 2. The effect of temperature on the UCS

As the 9 M NaOH concentration with 14. 86 % water content showed the highest UCS; these conditions were used to investigate the effect of temperature variation. Figure 2 shows that as the curing temperature increases so is the UCS up to 80 ˚C and then there was a decline in UCS when the temperature was increased to 100 ˚C. The change of UCS with curing temperature can be explained by the underlying mechanism in alkaline activation. This is due to the increase in curing temperature helps accelerate the dissolution of silica and alumina species and then polycondensation. As the temperature increases to 100˚C, the polycondensation process becomes so fast and rapid formation of geopolymeric gel will hinder further dissolution of silica and alumina species and thus affect the UCS unfavorably [4]. Furthermore at elevated temperatures there rapid moisture loss that leads to incomplete alkaline activation. The masonry blocks cured at 40 ˚C still showed traces of moisture content which means the masonry block was not dry enough. Therefore the optimum drying temperature was 80 ˚C since it gave the highest UCS.

3.3. Effect of Curing Period on UCS

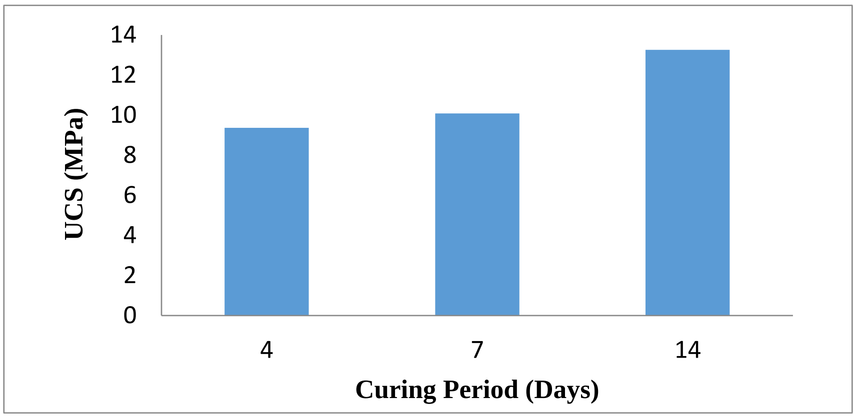

Figure 3. The effect of curing age on the UCS of the masonry blocks

Figure 3 shows that there was an increase in UCS with an increase in curing period. The results show that the masonry block reached their ultimate UCS in 14 days and a major portion of the UCS (about 76%) is gained within only 7 days and in 14 days the UCS reached 13.26 MPa. This means that enough time was allowed for dissolution of aluminosilicate in the geopolymeric gel hence the UCS was high compared to 4 and 14 days. The masonry block cured for 14 days at 80 °C satisfied the requirements of ASTM C34-13 with bulk density of 1578 kg/m^3.

3.4. XRF analysis before and after alkaline activation

Table 1. the effect of alkaline activation on chemical composition of Au MT

Component	Raw Au MT (Mass %)	Au MT after alkaline activation
Na_2O	0.3511	19.3434
MgO	3.7519	4.0103
AL_2O_3	10.9919	8.4790
SiO_2	45.5128	34.6241
P_2O_5	0.0836	0.0473
SO_3	4.0559	2.2666
Cl	0.0184	-
K_2O	4.0559	5.8760
CaO	8.7444	7.3728
TiO_2	0.9363	0.8128
Cr_2O_3	0.4254	0.4256
MnO	0.3998	0.4499
Fe_2O_3	14.8064	15.0894
CO_2O_3	0.0422	-
NpO	4.1577	-
CuO	0.0203	0.1230

ZnO	0.0265	0.0283
As_2O_3	0.7512	0.6644
Rb_2O	0.0361	0.0420
SrO	0.0272	0.0339
ZrO_2	0.0510	0.0446
Nb_2O_5	0.0068	-
BaO	0.1793	0.2479

Casting and curing at optimum conditions 9 M NaOH, 14 days curing period, 80 °C curing temperature and 14.37 % solid to liquid ratio shows that there was drastic change in the chemical composition of the masonry block. SiO2 changed from 45.51% to 34.62%. While Na2O changes from 0.3511% to 19.34%. The increase in Na2O was due to reasonable amount of a NaOH solution was introduced into the raw tailings during alkaline activation. These results reveal that there was enough dissolution of aluminosilicates, which resulted in more complete alkaline activation (Table 1).

3.5 FTIR analyses of gold mine tailings before and after alkaline activation

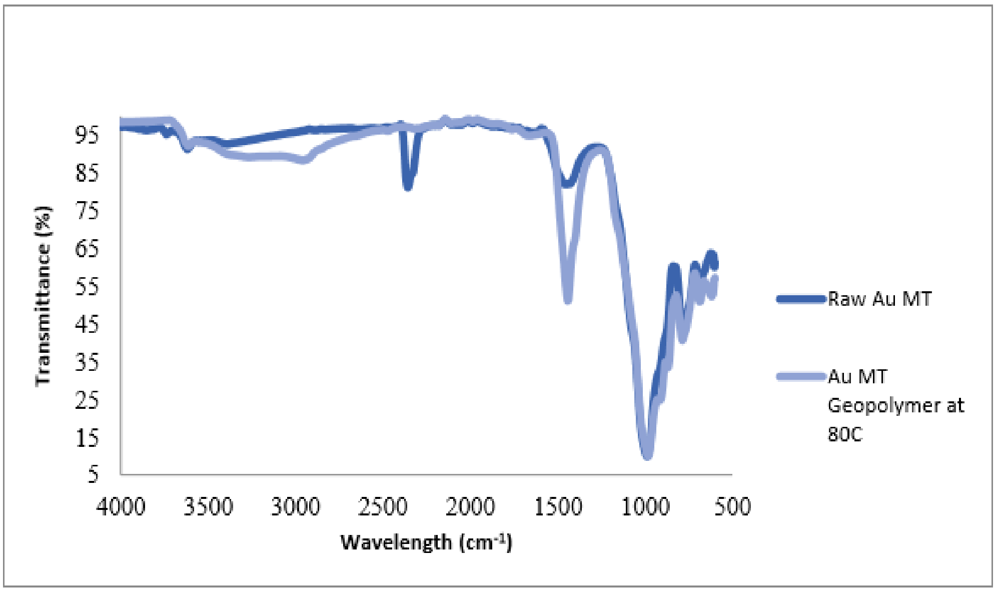

Figure 4. FTIR analyses of gold mine tailings before and after alkaline activation

Figure 4 shows the FTIR of gold mine tailings before and after alkaline activation. The raw gold mine tailings showed that the transmittance dropped until 81% at the wavelength of 2357 cm-1. The broad bands appearing at 1000 - 2535 cm−1 were due to stretching vibrations OH and HOH [5]. At 1442 cm^{-1} the transmittance for the alkaline activated sample was 52%.

3.6. The morphology of Gold mine tailings before and after alkaline activation

Figure 5 shows the SEM micrograph of Au tailings before alkaline activation. Figure 6 shows the effect of alkaline activation on the morphology of Au tailings. It can be seen that alkaline activation resulted in a dense construction block with some unreacted white particles revealing that alkaline activation was incomplete. The existence of pores was detected in this sample.

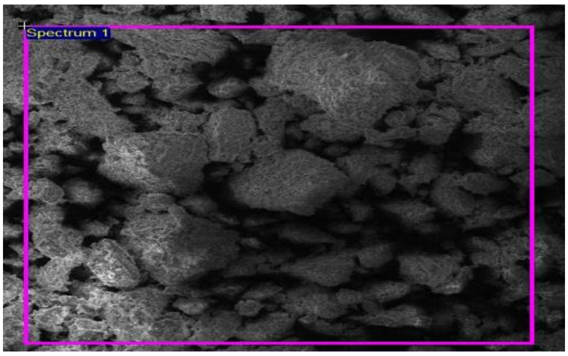

Figure 5. SEM for Raw Au Tailings

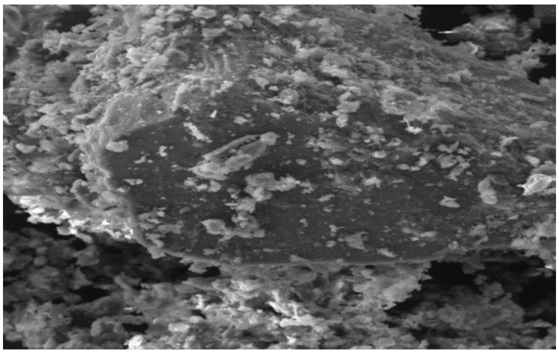

Figure 6. SEM after alkaline activation of Tailing at 80 ℃

4. Conclusion

Based on the experimental results the optimum conditions to develop a stabilized and solidified mansonry block with high UCS was at 14.31% S/L and 9 M NaOH concentration and 80°C curing temperature. This is due to a decrease in S/L ratio results in low workability of the paste which in turn decrease the UCS. Higher NaOH concentration provides larger amount of NaOH at a certain initial water content required for alkaline activation of gold mine tailings. Curing temperature is an important factor affecting the alkaline activation process and the UCS of masonry block. The UCS increases with the curing temperature up to a 80°C na d decreases. With regards to curing period, masonry blocks reached their ultimate UCS within 14 days and a major portion of the ultimate UCS (about 90%) is gained within only 4 days. Therefore the produced masonry block meet ASTM standards and can be used for building and construction purposes such as the building of structural clay load bearing wall tiles of all C34-03 ASTM designation grades and building blocks of ASTM designation C6210, type NW (negligible weathering) with the minimum UCS of 10.3 MPa [6].

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