Cement and fly ash stabilised gold mine tailings for the development of new material

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Abstract

More than 500 gold tailings and a number of fly ash dumps exist in South Africa. These waste material contribute significantly to air, water and soil pollution. In this study gold mine tailings and fly ash which are readily available and result into environmental pollution were used to produce new building/construction material. The tailings were stabilised with cement and fly ash. Up to 20% of cement was incorporated in the mix design. The incorporation of 20% cement resulted into significant unconfined compressive strength (UCS) improvement of 3.89 MPa and 4.36 MPa at 56 and 90 days of curing, respectively. The strength development in fly ash and cement modified tailings was influenced by the pozzolanic and hydration reaction. The strength developed is applicable for the materials to be used for load bearing. The unconfined compressive strength of the developed specimen the composites met the minimum SANS 2001-CM1:2007 for hallow bricks to be used as masonry bricks.

Key words: fly ash-cement, gold tailings, fly ash-cement, unconfined compressive strength and durability

Introduction

The production of gold generates a significant amount of tailings. Lee and Shang (2018) defined tailings as ground rock particles that remain after the extraction of valuable metals and minerals from the ore. Tailings are treated and stored in the tailings dams. Tailings dams are massive structures designed to contain the waste slurry remaining after processing ore at open pit and underground mines (Gerrit et al. 2017). Tailings storage facilities pose environmental hazard; exposure to the contaminants occur through ingestion of contaminated food and water, wind-blown dust, erosion to surface water bodies and inhalation by humans (Schonfeld et al. 2014; Gitari et al. 2018). The communities living around these tailing storage facilities are exposed to environmental hazards and the development of technologies that can utilise tailings to minimise the environmental hazard while beneficiating the environment might solve the related issues (Gitari et al. 2018).

Hence several researchers have attempted to minimise the harmful effect of tailing dams by beneficiating the tailings in a sustainable manner (Mahmood and Elektorowicz 2017). Fly ash is one of the readily available solid wastes and classified into two grade; class C and class F fly ash. Class F is mostly used with cement as an activator to produce cementious product as it contains low CaO content. Amu et al. 2015 investigated the potential of utilising cement and fly ash mixture to stabilise expansive clay soil. The study focused on clay soil treated with 12% cement, clay soil stabilised with 9% cement plus 3% fly ash and unstabilized clay was used as reference. The samples were tested for maximum dry density (MDD), optimum moisture content (OMC), undrained triaxial, unconfined compressive strength (UCS) and California bearing ratio (CBR). The composite with cement and fly had better MDD, OMC, CBR and UCS results compared to the one with cement alone. It was concluded that the use of cement with fly ash improve the stabilization of expansive soil.

Jayakumar and Sing 2012 used fly ash and cement stabilised treated sub-base soil for sustainable design recommendation. 2%, 4% and 6% of cement were used to stabilise the soil while fly ash used at 6% to stabilise the soil and the soil was stabilised with a mixture of fly ash and cement each at 3% by weight. Tests conducted on the composites include the standard proctor test, hydraulic conductivity, unconfined compression strength and California bearing ratio. The addition of fly ash and cement significantly improved the UCS and CBR and fund to be economical. Xiao et al. 2017 investigated the effectiveness marine clay stabilised with fly ash and cement. Tests including isotropic compression split tensile, bender element and unconfined compression tests were conducted to study the effectiveness of fly ash cement improved marine clay. The results indicated that the effectiveness of fly ash cement improved marine clay depends on the curing time, water content and cement content. Higher strengths were obtained at 50-100% cement and 90-150 days curing period while the optimum isotropic compression was yielded at 90 days curing with over 60%. Cho et al. 2019 studied the effect of fly ash's chemical composition on the compressive strength of mortar stabilised with cement and fly ash. Compressive strengths were evaluated on the specimens that were prepared by replacing 25% of cement with 16 different types of fly ashes. The results showed that the compressive strength increased with the curing time and this was influenced by the difference in pozzolanic reactivity. The chemical analysis revealed that the glass phase (SiO_2, Fe_2O_3 and Al_2O_3) significantly affect the pozzolanic reaction. This study investigated the use of fly ash and cement to stabilise gold mine tailings for possible application in building and construction.

Materials and methods

Three materials were used; the treated gold tailings were collected from Pan African Resources Mine in Barberton, Mpumalanga. Fly ash was collected from Eskom, Camden power station in Ermelo. SUREBUILD cement was purchased from one of the suppliers in Gauteng. The materials were then characterised for elemental analysis using X-ray Flourescene (XRF). The standard compaction tests were conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) on the composites of fly ash: cement: gold mine tailings (45:5:50, 40:10:50, 35:15:50 & 30:20:50). The specimens were casted at their OMC and MDD using 50mmx50mm moulds. The cast were sealed in a plastic (to prevent loss of moisture) for curing periods of 3, 7, 14, 28, 56 and 90 days at room temperature in order to study the effect of curing time. The Unconfined Confined Compressive strength was measured using a UCS machine with a loading rate of 15 kN/min. The composites were subjected to 7 wet and dry cycles. The cured specimens were characterised for mineralogy using X-ray diffraction (XRD) and morphology by Scanning Electron Microscope (SEM) to investigate and study the formation of the reaction products of the stabilised gold tailings and the relationship between the UCS and products from the pozzolanic and hydration process.

Results and discussion

The chemical compositions of the raw materials; fly ash, gold tailings and cement are given in

Table 1.

Table 1. Elemental analysis of the raw materials

Materials	CaO	Al_2O_3	MgO	SiO_2	MnO	Fe_2O_3
GT	9.17	11.25	4.64	48.08	0.32	14.87
CEMENT	47.96	13.34	2.16	26.28	0.38	4.05
FA	10.52	19.43	1.39	46.57	0.12	15.58

GT= gold tailings, FA= fly ash, C=cement

Table 1 gives the chemical compositions of the raw materials from XRF analysis, the tailings has a high proportion of silica, followed by iron oxide and alumina at 14.87%, 11.25% respectively. These elements play a vital role in the stabilisation of soil. The most distinctive component about fly ash is the calcium oxide content which in this case is lower 25% and it is classified as class F fly ash. Class F fly ash is not self-cementing and requires an activator (CaO) in order for it work effectively and the significant proportion of silica and aluminium makes it a pozzolanic material. Cement has high proportion of calcium oxide at 47.96% which is one of the significant components in pozzolanic and hydration reaction responsible for strength development.

Standard compaction test

Figure 1 presents the compaction curves for Maximum Dry Density and Optimum Moisture Content of fly ash- cement stabilised gold tailings.

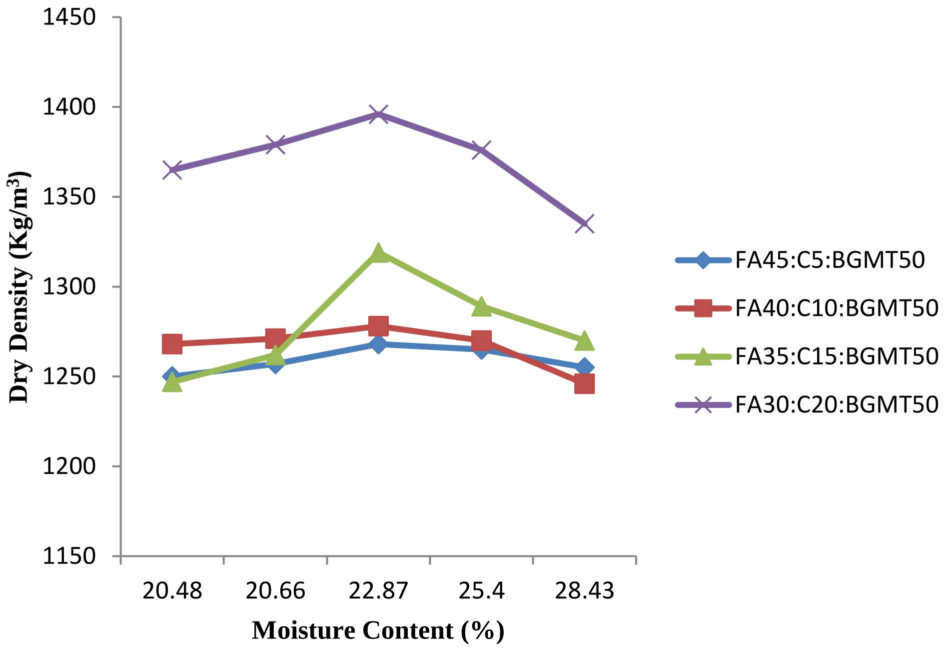

Figure 1. Compaction curve for fly ash- cement stabilised tailings

The gold tailings were stabilised with four different proportions of fly ash: cement (45:5, 40:10, 35:15 and 30:20) at constant gold tailings 50%. The maximum dry density (MDD) increased as the cement content is increasing and fly ash content decreases. The optimum moisture content (OMC) decreases as the cement content was increased while it increases as fly ash content is increased. MDD of 1396 kg/m^3 was obtained at 20% addition with an OMC of 22.87%. The trend was observed by many researchers (Jayakumar and Sing 2012; Amu et al. 2005; Arulrajah et al. 2017).

Unconfined compressive strength of the different ratios

Table 2 present the unconfined compressive strength of gold tailings stabilised with different proportion of fly ash: cement.

Table 2. UCS of fly ash- cement stabilised gold tailings

Ratios (%)	UCS (MPa)
FA45:C5:GT50	0,36
FA40:C10:GT50	1,32
FA35:C15:GT50	1,76
FA30:C20:GT50	2,04

Gold mine tailings were stabilsed with different proportion of fly ash and cement in order to determine the best ratio that improves the unconfined compressive strength (UCS) of gold tailings. The UCS increases significantly with the increasing content of cement and increased rapidly from 0.36 MPa to 2.04 MPa at 5 to 20% cement respectively. UCS decrease is observed as the fly ash content the increase. The strength decrease with the increasing content of fly ash is related to the hydration and pozzolanic reaction (Xia et al. 2017). The strength decrease with increasing content of fly ash was attributed by the reduction of cement content and with higher content of fly ash more portlandite is produced which is not favorable to the cement mechanical properties and lower pozzolanic activities Bei et al. 2016 aggred that pozzolanic activity cement is affected by lower pozzolanic activity hence strength decrease (Wu et al. 2014).

Strength development of gold tailings stabilised by fly ash and cement

The best composite of fly ash, cement and gold tailings (30FA: 20C: 50GT) was casted and strength development was studied. The results for strength development of fly ash-cement stabilised gold tailings are presented in figure 2. The unconfined compressive strength (UCS) increased with the curing time of which was expected. The UCS increased by more 100% from 3 to 28 days curing period. UCS of 2.04 MPa to 3.12 MPa was reported from 3 and 28 days respectively. The strength development in fly ash and cement is influenced by the pozzolanic and hydration reaction. When cement react with water it forms the calcium aluminates hydrates (CAH) and calcium silicate hydrate (CSH) and the pozzolanic reaction resulting from fly ash and cement forms the CSH and CAH products that continue to increase with curing time and increase the UCS strength of the composites (Yoobanpot et al. 2017; Wu et al. 2014; Pastor et al. 2016; Liu et al., 2019). The formation of hydration and cementitious products is confirmed by the XRD analysis in figure 4.

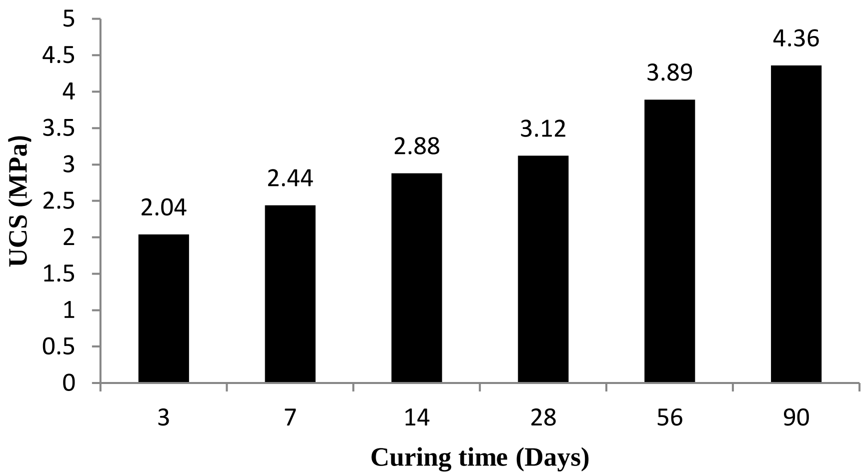

Figure 2. Strength development of fly ash- cement stabilised gold tailings

SEM analysis of fly ash cement stabilised gold tailings

Figure 3 shows the micrographs of fly ash cement stabilised gold tailings at 3 and 28 days curing period.

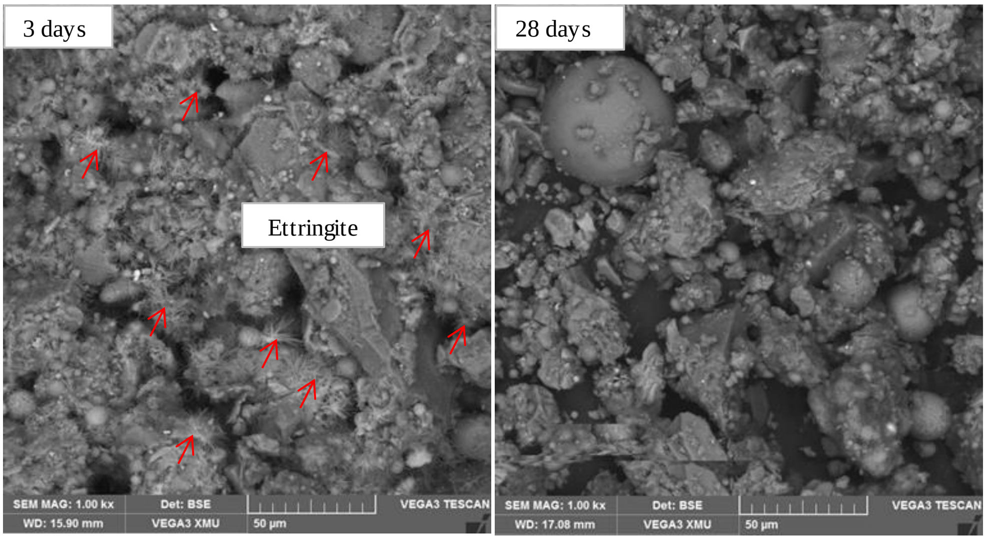

Figure 3. SEM micrographs for 3 and 28 days curing period.

Figure 3 shows the micrographs of the stabilised tailings, the addition of fly ash and cement resulted in a significant change on the microstructure of the composite. The hydration products depicted from XRD are evident on the micrographs; the Ettringites which are responsible for strength gain in the early hydration represented by needle-like crystal are visible on the micrograph of the early curing period at 3 days. The hexagonal structures representing the CAH were observed and the presence of fly ash (the spherical structures) is also visible which is distributed together with the CAH product on the micrograph of the 28 days curing period which also improved the soil structures resulting in strength gain (Yoobanpot et al., 2017; Liu et al., 2019), these observations confirmed the XRD results.

XRD analysis

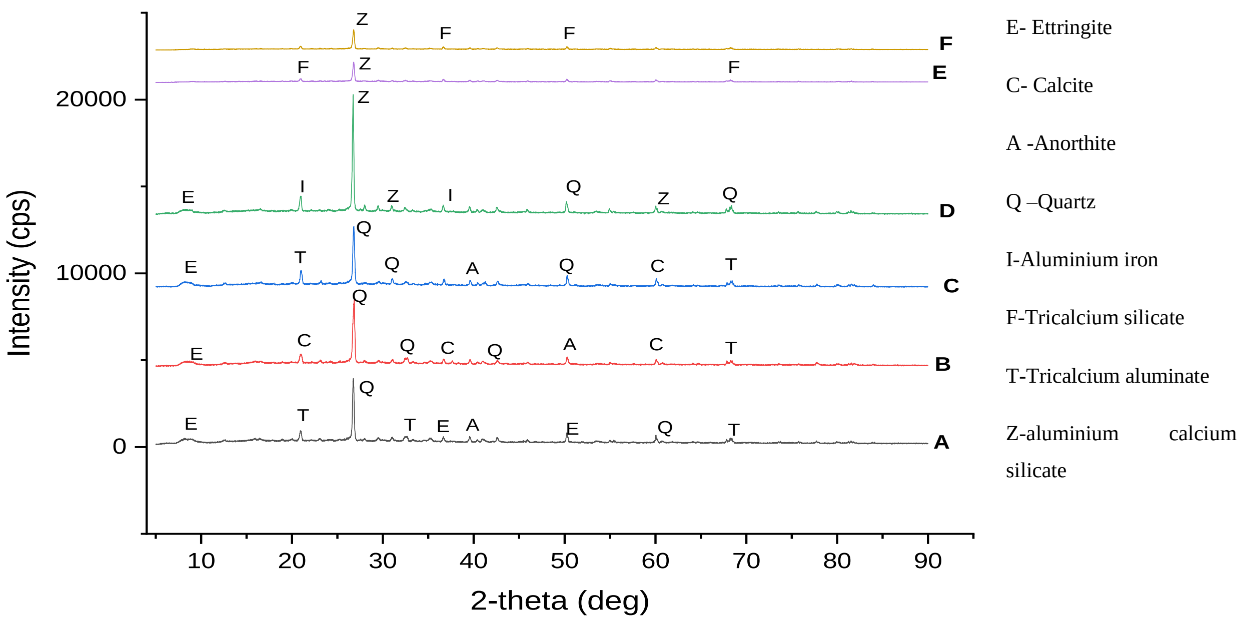

Figure 4. XRD analysis for BGMT stabilised with FA and Cement: (A) 3 days (B) 7 days (C) 14 days (D) 28 days (E) 56 days and (F) 90 days curing

Wet and dry cycles

Figure 5 shows the results for the wet- dry cycles that the composites were subjected to. The cured composites of fly ash, cement and gold tailings were cured and subjected to 7 cycles. The composites reached optimum unconfined compressive strength after 3 cycles but there was strength loss after 5 and 7 cycles this shows that there is strength decreases with longer weathering period (Ashraf et al., 2018) and the shape of the specimens remained intact throughout the cycles.

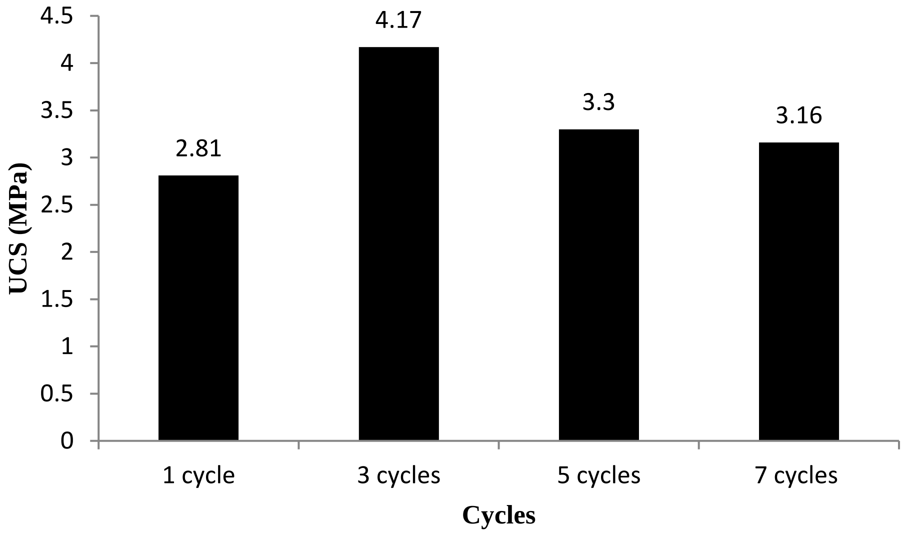

Figure 5. Wet and dry cycles of fly ash cement stabilised gold tailings

Conclusions

The UCS of the fly ash- cement stabilised gold tailings increased with the curing time. The unconfined compressive strength of 3.12 MPa after 28 days curing for the composite can be used as masonry walling as hallow bricks according to SANS 2001-CM1:2007. The XRD analysis showed the formation of hydration and pozzolanic products. The addition of fly ash and cement had a significant effect of the tailings structure. The UCS results agreed with the XRD analysis and SEM observations. The compressive strength did not show major strength degradation after the durability test.

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