Enhancement of the geotechnical and geochemical properties of gold tailings by BOF slag and class F fly ash

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Abstract

The aim of the study was to study if gold tailings can be stabilised by fly ash. The gold tailings used in the study was the one where gold was recovered by cyanidation process. With more than 500 gold tailings in South Africa, which has adverse effect on the environment and human health, this study provided a potential solution to deal with the tailings. Fly ash and BOF slag were investigated as stabiliser to improve the properties gold tailings. Different fly ash: gold tailings: BOF slag mix designs were investigated. Specimens were cast using the optimum ratio and cured for 3, 7, 14, 28, 56 and 90 days to study the effect of curing time on strength development and after the UCS tests the composites were characterised. The composite with 10% fly ash, 40% BOF slag and 50% gold tailings showed the highest unconfined compressive strength. The composite can withstand 5 wet-dry cycles. The BOF slag and FA modified GMT meet the minimum strengths requirements to be classified as C4 material which can be used as subgrade material.

Key words: beneficiation, gold mine tailings, slag, stabilisation

Introduction

Considerable volumes of waste materials generated by numerous industrial activities is disposed to the environment resulting to pollution (Mashifana et al 2018). The mining sector in South Africa contributes greatly to the economic development of the country. Researchers specifically identified gold mining industry for over years playing a significant role in the country's economic development (Schonfeld et al. 2014; Ngole-Jeme and Fantke 2017) and the production of gold generates significant amount of tailings (mine residues). The impact of gold mine tailings to the environment were investigated, the results showed that tailings pose serious human health risk and ecological hazard through the inhalation of tailing dust and ingestion of contaminated food/soil/water (Ngole-Jeme and Fantke 2017; Rudzani et al. 2017). Some residents living around the tailing dams complained about wheezing chest, chronic cough, dermatitis and flu and risk of long term effect such as cancer. There is a need to develop solutions that will utilise the tailings and minimize the impact posed by gold tailings.

Fly ash and BOF slag as an industrial wastes were used in this study to beneficiate the gold tailings. Fly ash is the by-product of coal combustion during the production of electricity and it is either disposed in the landfill or stored at the power plant (Chancey et al. 2010; Xiao et al. 2017; Cho et al. 2019). All the three wastes utilised in this study, gold mine tailings and fly ash are by-products that are readily available and are disposed in the landfill and result into polluting the environmental. The materials have constituent that certify them to be used in civil construction producing products at low cost and minimizing the environmental impact.

BOF slag is mostly used in the production of cement and road construction. Carvhalo et al. 2017 evaluated the effect of utilizing BOF slag in the production of Portland cement. Specimens were casted by adding 0, 1.8, 3.6 and 5.4% BOF slag to the slag cement. The axial compressive strength was tested at 3, 7, 28 and 91 days of hydration, the specimens were also characterised by setting time, hot and cold expansibility. The addition of BOF slag improved the strength of the material but 5.4% addition had the greatest gain. In 2016 Santamaría et al. investigated the use of fly ash and steel slag in structural mortars. Mortars were prepared using steel slag to substitute aggregate and used as a cementing material and fly ash was used with Portland cement. The use of steel slag with fly ash- cement appeared acceptable and the strength reached about 78 MPa. The results showed that there is a potential of using steel slag with fly ash in structural mortars.

Li et al. 2018 prepared fly ash- slag-carbide binder for application in mine backfilling. The optimum composite was composed of 62% fly ash, 20% slag, 10% compound activator and 8% carbide slag. Compressive strength of 1.64- 4.14 MPa was obtained at 28 days hydration. The cost of the backfill was found to be 20% lower compared to the one with Portland cement alone. Researchers have used BOF slag and fly ash for cement production and the use of BOF slag with fly ash to stabilise tailings is not explored. This study focused on using waste to beneficiate waste in order to produce products that can be used for building purposes.

Materials and methods

The gold tailings were collected from Pan African Resources Mine in Barberton, Mpumalanga (South Africa). Fly ash was collected from Eskom, Camden power station in Ermelo (South Africa). The BOF slag was collected at Vaal, Arcelo Mittal. The materials were then characterised for chemical composition 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: BOF slag: gold mine tailings (10:40:50, 20:30:50, 30:20:50, 40:10:50 & 25:25:50).

The specimens were compacted at their OMC and MDD using 50x50x50mm^3 moulds. The specimens were sealed in a plastic for curing periods of 3, 7, 14, 28, 56 and 90 days at room temperature in order to study the strength development with curing time. The unconfined compressive strength (UCS) was measured using a UCS machine with a loading rate of 15 kN/min.

Results and discussion

Table 1 present the chemical composition of the materials

Table 1: XRF 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
BOF	47.50	4.20	3.62	10.15	3.94	27.73
FA	10.52	19.43	1.39	46.57	0.12	15.58

GT = gold tailings, BOF = basic oxygen furnace, FA = fly ash

The elemental compositions of the materials are presented in table 1. The predominant compounds in gold tailings are silicon oxide 48.08%, iron oxide 14.87%, alumina 11.25% and calcium oxide 9.17%. The main constituents of BOF slag are CaO (47.50%), Fe_2O_3 (27.73%) and SiO_2 (10.15%), the high proportion of CaO is attributed to lime that is added in the furnace in order to remove unwanted chemicals and iron that was not recovered when steel was made from the molten iron (Yildirim and Prezzi 2011; Jiang et al. 2018). Fly ash is mainly distinguished by the CaO (10.52%) content from the chemical composition presented in table 1 it is evident that a class F fly ash was used in this study as the proportion of CaO is less than 25%.

Standard compaction curve for different mix ratio of BOF: FA: GT

The maximum dry density (MDD) and optimum moisture content (OMC) of the mixtures obtained from the standard compaction test is shown in figure 1.

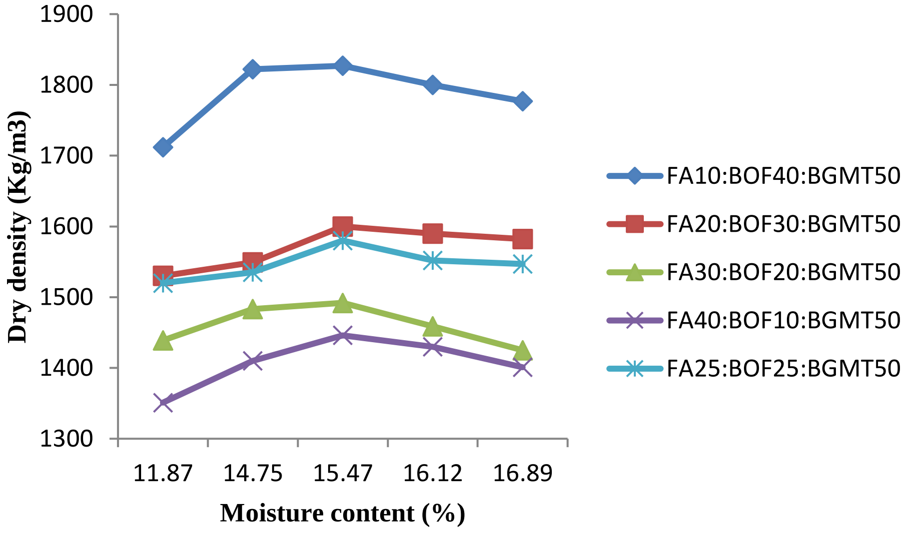

Figure 1: MDD and OMC for different mix designs

Standard compaction test was done on the mixture of tailings, BOF slag and fly ash in order to determine the MDD and OMC. The BOF slag and fly ash content was varied between 10-40% while keeping the gold tailings constant at 50%. The OMC of the composite increase with the increasing content of fly ash and it is opposite for the BOF slag content. The MDD of composite decrease as the fly ash content increase from 10-40% at decreasing BOF slag content from 1827 to 1446 kg/m^3 while the MDD increases as the BOF slag content increased the results are in parallel with the previous research (Kumar and Rao 2017; Zumrawi and Babikir 2017). The behaviour of fly ash is attributed to its lower specific gravity and the smooth spherical particles that fill the voids which turn to produce denser matrix (Lee et al. 2014). The decrease in OMC is attributed by the agglomeration of particles that makes it easy to reach compaction with less water and increase in MDD is attributed by its higher specific gravity (Akinwumi 2014).

Unconfined compressive strength of the different ratios

Figure 2 shows the unconfined compressive strength of the different mixtures of BOF slag, gold tailings and fly ash. The obtained MDD and OMC for each mix design were used to cast and cure specimen in order to determine the best ratio that can stabilise the gold tailings. The UCS of the ratios increased with the increasing content of BOF slag and decreasing content of fly ash. The best ratio was found to be FA10: BOF40: GT50 with a UCS of 1.04MPa. The XRF analyses were conducted on the composites in order to study the influence of chemical composition on the UCS. From the chemical composition presented in table 2 increasing the BOF slag content increases the CaO content while decreasing the SiO_2 and Al_2O_3 content and in turn increase the Ca: Si ratio while decreasing the Al: Ca which are responsibly for strength gain (Sekhar and Nayak, 2019).

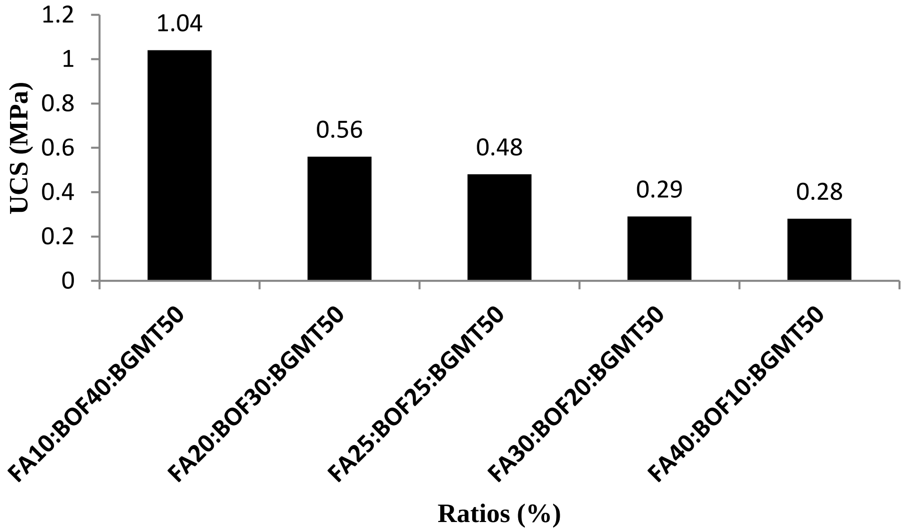

Figure 2: UCS of the composites

Table 2 present the XRF analysis of different mixtures and ratios of Ca: Si & Al: Ca for the mixtures

Table 2: XRF analysis and ratios of Ca: Si & Al: Ca

Composites	10B:40FA:50GT	20B:30F:50GT	25B:25FA:50GT	30B:20FA:50GT	40B:10FA:50GT
CaO	11.83	14.22	15.56	16.60	17.70
SiO_2	43.70	42.09	40.51	39.99	39.11
Al_2O_3	17.64	16.48	15.54	14.85	12.77
Ratios of Ca:Si and Al: Ca for the composites					
Ca: Si	0.27	0.34	0.38	0.42	0.45
Al: Ca	1.49	1.16	0.99	0.89	0.72

Strength development of the optimum composite

Figure 3 shows the strength development of the optimum ratio of BOF slag, fly ash and gold tailings over time. The UCS of the composite increased with the curing time. The UCS significantly increased by 40% from 1.04MPa at 3 days curing period to 1.42MPa after 56 days of curing. The obtained results are in parallel with other researches (Li et al., 2018; Jiang et al., 2018; Santamaría et al., 2016; Wang et al., 2018). The strength gain of BOF slag and fly ash stabilised composites is attributed by materials cementious structure which is caused by the product of hydration reaction, pozzolanic and crystallisation (Rabbani et al., 2012). The chemical compositions were used to study its influence on the UCS of the composites over time as Sekhar and Nayak, 2019 stated that Ca: Si and Al: Ca can be used to justify strength development. The increase in Ca and decrease in Al confirms the strength gain as the trend confirms the production of cementious compounds (CAH and CSH) (Sekhar and Nayak, 2019). The strength gain is attributed to increase in Ca: Si and decrease in Al: Ca which is confirmed in table 3 (Sekhar and Nayak 2019; Jha and Sivapullaiah, 2014).

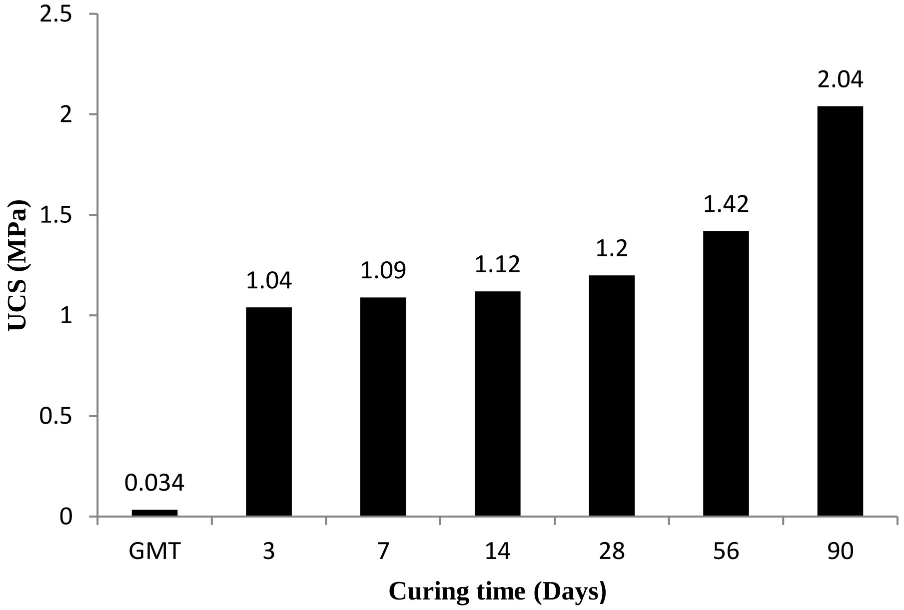

Figure 3: Strength development (FA 10: BOF 40: GMT 50)

Table 3: Ratios of Ca: Si & Al: Ca

Composites	3 days	7 days	14 days	28 days	56 days	90 days
Ca: Si	0.45	0.54	0.55	0.58	0.60	
Al: Ca	0.72	0.57	0.53	0.52	0.48	

Wet-dry cycles of the BOF: FA: GT composite

Environment plays a significant role in building and construction material especially subject to weathering on wet and extreme temperatures the test had to be conducted to evaluate if the composite can withstand such conditions (Zhang and Zong 2014). The results for wet-dry cycle are presented in figure 4.

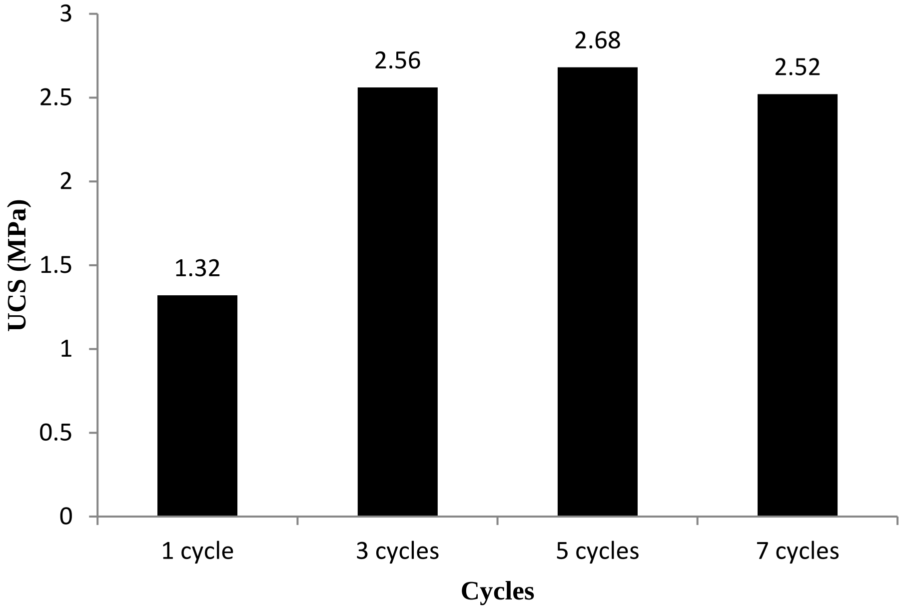

Figure 4: Wet-dry cycles for the composites (FA 10: BOF 40: GMT 50)

The composite FA10: BOF40: GT50 was subjected to 1, 3, 5 and 7 cycle of wet-dry and the UCS results of the cycles are presented in figure 6. The highest UCS of 2.68MPa was obtained after 5 wet-dry cycles, which means it can withstand over 10 days of wetting and drying without losing strength but gaining. The strength loss after was obtained after 5 cycles which did not show major difference.

Conclusions

The OMC of the composite increased with the increasing content of fly ash and decreased with the increasing BOF slag content. The MDD of composite decreased as the fly ash content increased from 10-40% while the MDD increased as the BOF slag content increased. The best ratio was found to be FA10: BOF40: GT50 with a UCS of 1.04 MPa. The UCS of the composite increased with the curing time. The strength gain is attributed to increase in Ca: Si and decrease in Al: Ca. The optimum temperature was found to be 80°C. The composite can withstand 5 wet-dry cycle

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