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The PGM tailing remedy for potential economic end-use

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Abstract

Most tailings materials although reprocessed for economical gain, continue to cause pollution. The tailings material continues to cause acidic rock drainage impacting catchments and the river systems. Furthermore, tailings material contaminates underlying and adjacent land with the heavy metals and dust. This further affects roads and other structures impacting the community living in proximity to around the tailing's storage facilities. Tailings materials also cause land degradation making it unproductive. Many of the mining companies that created the dumps have closed and the cleaning-up responsibility now lies with the Department of Mineral Resources and Energy (DMRE) which lacks the financial capacity to undertake clean-up. The clean-up cost for all the mine dumps using conventional methods has been estimated by the United Nations as USD 60 billion.

This study examines the feasibility of using tailings material to manufacture construction bricks and tiles, to mitigate the issue of continuous pollution. This study hopes to reduce the pollution caused by tailings material on river systems, land, and improve the health and well-being of the community's achieving rehabilitation of mines and environment. This study examines the feasibility of the platinum group metals (PGMs) tailings material rehabilitation in the Rustenburg area of South Africa. The PGM tailings material was analysed using the X-ray fluorescence (XRF) and X-ray diffraction (XRD) to uncover the chemical composition. The metallurgical test work was conducted to maximize value recovery from the platinum group metals (PGMs) tailings. Furthermore, a design mix was established and ultimately engineering applications were undertaken to test for the viability of the manufacturing construction bricks and tiles using the PGM tailings materials. This study further states that the sale of bricks would create a circular economy and empower surrounding communities through entrepreneurship.

Keywords: PGMs, Tailings, Bricks, Economic, Environmental

1 Introduction

1.1 Background

The extraction and production of PGMs result in substantial quantities of tailings, which pose significant environmental and economic challenges. Traditional tailings management practices involve storage in impoundments or tailings dams, which can be costly, resource-intensive, and carry the risk of environmental contamination. This paper explores the alternative of utilizing PGM tailings for economic end-use, reducing the environmental impact and creating new value streams.

The growing concerns over environmental degradation and rising unemployment rates have become significant challenges in the modern world. As society grapples with the negative consequences of industrial activities, there is a pressing need for sustainable solutions that not only mitigate pollution but also address the issue of unemployment and infrastructure. In this paper, we propose a novel approach that harnesses the potential of Platinum Group Metals (PGMs) tailings to manufacture construction bricks, aiming to tackle both pollution and unemployment simultaneously.

In recent years, the world and especially Africa has been struggling with critical challenges such as environmental pollution and rising unemployment rates and low growth rate in infrastructure. The urgent need for innovative solutions to combat these issues has become a paramount concern for governments, industries, and societies at large. One promising avenue of exploration lies in the transformation of platinum group metals (PGMs) tailings, a waste product generated by the mining industry, into construction bricks that not only address pollution concerns but also offer employment and infrastructure development opportunities.

The transformation of PGMs tailings into construction bricks holds significant promise in addressing the challenges of pollution, unemployment, and infrastructure. This paper aims to explore the technical feasibility, environmental benefits, and socio-economic impacts of adopting this innovative approach.

The accumulation of PGMs tailings poses environmental risks due to their potential to release toxic elements into nearby ecosystems, (Minetek 2023). In recent years, the world and especially Africa has been grappling with critical challenges: Environmental pollution has been one of the major issues of mine tailings and rising unemployment rates. The urgent need for innovative solutions to combat these issues has become a critical for governments, industries, and societies at large. One promising avenue of exploration lies in the transformation of platinum group metals (PGMs) tailings, a waste product generated by the mining industry, into construction bricks that not only address pollution concerns but also offer employment opportunities.

a. **Contamination of water system:** tailings can lead to their release into nearby rivers, lakes, or other water bodies. The tailings can introduce various pollutants into the water, such as heavy metals (e.g., lead, mercury, arsenic) and chemical reagents (e.g., cyanide, sulfuric acid). These substances can have toxic effects on aquatic life, disrupt ecosystems, and render water unfit for drinking, irrigation, or recreational use. (Minetek 2023).

b. **Acid mine drainage:** mining operations, such as those involving sulphide minerals, can produce acid mine drainage when tailings get rained on. (Minetek 2023).

c. **Air Pollution:** with time, tailing dumps safety deteriorate due to maintenance. The smallest particles are blown out by the wind causing air pollution.

d. **Land contamination:** in the same token, the blown-out particles by wind, pollute the near land that could serve for agriculture. (I.Licsko L. Lois and G. Szebenyi 1999).

The utilization of PGMs tailings for brick manufacturing fosters economic development, employment opportunities and eradicate pollution by establishing full mines rehabilitation. Local communities residing near mining sites often bear the brunt of unemployment due to limited job prospects outside the mining industry. By implementing tailings-based brick production facilities, we can create a new sector that not only leverages the existing mining infrastructure but also generates sustainable livelihoods for local workers. This can lead to improved socio-economic conditions, reduced dependence on the mining sector, and enhanced community resilience.

Furthermore, this can also develop the community infrastructure such as dissent housing and spacious, recreational centres, stadiums, Schools, and hospitals.

The objectives of this study are:

- to perform a comprehensive chemical analysis of the platinum group metals (PGMs) tailings material. This analysis will involve identifying and quantifying the presence of various elements, compounds, and contaminants within the tailings. The results will contribute to a deeper understanding of the composition and potential environmental impact of the tailings.
- to investigate the physical properties of the PGM tailings material. This will involve assessing parameters such as particle size distribution, density, and specific gravity. By examining these physical characteristics, the study aims to provide insights into the material's stability, behaviour, and potential for different applications or processes.
- The study will also focus on evaluating the environmental implications of the PGM tailings material. This includes examining the potential for leaching of harmful substances into the surrounding soil, water, and air. By understanding the environmental risks associated with the tailings, the study aims to contribute to sustainable management and mitigation strategies.
- to explore potential utilization options for the PGM tailings material. This could involve investigating its suitability for reuse in various industries or as a raw material for manufacturing construction bricks. By identifying viable utilization pathways, the study aims to contribute to waste reduction and resource optimization.

Based on the findings from the chemical analysis, physical properties assessment, environmental implications evaluation, and utilization exploration, the study aims to provide informed recommendations for the management of PGM tailings.

2 PGM tailings: composition and characteristics

2.1 Formation of PGM tailings

Platinum Group Metals (PGMs), comprise platinum, palladium, rhodium, ruthenium, osmium, and iridium, have significant industrial applications, particularly in the automotive and electronics sectors. The mining and processing of PGMs generate substantial tailings, which are often treated as waste. PGMs in South Africa occur in the Bushveld Igneous Complex.

2.2 Chemical characteristics

Silicon dioxide (SiO_2) is a chemical compound consisting of silicon and oxygen. It is commonly known as silica. SiO_2 is one of the most abundant compounds on Earth and can be found in various forms, including quartz, sand, and glass.

SiO_2 is widely used as a bonding material due to its excellent chemical and physical properties. It possesses high thermal stability, good electrical insulation, and strong mechanical strength. These properties make it suitable for various applications, such as: glass manufacturing, adhesives and sealants, catalysts support, abrasives and polishing agents. (Saidov T.A and Sharipova A.R 2019).

Cr2O3 refers to chromium (III) oxide (Cr_2O_3), also known as chromia. It is a chemical compound composed of two chromium atoms bonded to three oxygen atoms. Cr_2O_3 is commonly used as a bonding material in various applications due to its high melting point, thermal stability, and resistance to corrosion.

One potential application of Cr2O3 as a bonding material is in the production of ceramic materials. It is often utilized as a refractory material, which can withstand high temperatures and harsh environments. For example, Cr2O3 can be employed as a binder in the manufacturing of refractory bricks used in the construction of furnaces, kilns, and other high-temperature equipment. (Kapoor A and Sharma 2018).

According to Kapoor Sharma, "Chromium oxide (Cr2O3) is widely used as a bonding material in the production of ceramic materials due to its excellent thermal stability and resistance to corrosion" (p. 123).

Fe_2O_3 is a chemical compound known as iron (III) oxide or ferric oxide. It is composed of two iron (Fe) atoms bonded to three oxygen (O) atoms. Fe2O3 is commonly found in nature as the mineral hematite and is known for its reddish-brown color.

One of the main uses of Fe2O3 is as a bonding material in various applications. It is often utilized as a binder in the production of abrasives, such as grinding wheels and sandpaper, where it helps hold the abrasive particles together. Additionally, Fe2O3 is used in the manufacturing of ceramic materials, pigments, and as a catalyst in chemical reactions. (Sciencedirect 2018).

MgO, or magnesium oxide, is a compound consisting of magnesium (Mg) and oxygen (O). It is commonly used as a bonding agent in brick materials due to its favourable properties such as high melting point, excellent thermal stability, and strong bonding capabilities.

One study discussing the use of MgO as a bonding material in bricks is conducted by Ahmad Z. and al. (2019). In their research titled "Effect of Magnesium Oxide on Properties of Alkali-Activated Slag Mortars," the authors investigate the effects of MgO addition on the properties of alkali-activated slag mortars used in brick production. (David S.M.; Miguel B; Rui V.S.; Jose R.J. 2022).

According to David and al. (2022), MgO acts as a chemical activator, promoting the hydration and hardening process in alkali-activated slag mortars. The addition of MgO improves the compressive strength, durability, and bonding properties of the brick materials. This makes MgO a crucial component in enhancing the performance and longevity of brick structures.

2.3 Health concerns of PGM tailings material

PGM tailings material contains Cr_2O_3, known as chromium (III) oxide. It is a chemical compound that contains the element chromium. In construction bricks, chromium (III) oxide is typically used as a pigment to provide coloration.

In its trivalent form (chromium (III)), chromium is generally considered to be less toxic and has lower health implications compared to its hexavalent form (chromium (VI)). Hexavalent chromium is a known human carcinogen and can cause respiratory, skin, and gastrointestinal irritation, as well as other adverse health effects. However, it's important to note that under certain conditions, chromium (III) can oxidize to chromium (VI), which is a more toxic form (Agency 2000).

In the case of construction bricks containing Cr_2O_3 as a pigment, the risk of exposure to harmful levels of chromium is generally low. The chromium (III) oxide used in bricks is typically chemically stable and not readily converted to the hexavalent form. Furthermore, the Cr2O3 pigment is usually bound within the brick matrix, reducing the potential for release and exposure. Making bricks out of PGMs tailings containing Chromium (III), will not affect the operator because of its stability. Proper safety majors for handling inhalable dust have to be observed while making the bricks such as masks, gloves and safety goggles.

In a natural environment, the transformation of Chromium (Cr) from the trivalent state (Chromium 3 or Cr (III)) to the hexavalent state (Chromium 6 or Cr (VI)) can occur through several processes. The most significant mechanism involves the oxidation of Cr (III) to Cr (VI) by various oxidizing agents present in the environment, such as certain bacteria, fungi, and certain chemicals (Scott and al. 2001). (Scott and al. 2001). In a study by Lakshmanan and al. (2017), the researchers investigated the ability of Pseudomonas aeruginosa to transform Cr (III) to Cr (VI) through enzymatic activity. study found that Pseudomonas aeruginosa expresses specific enzymes that facilitate the oxidation of Cr (III) to Cr (VI), contributing to the biotransformation of chromium compounds.

One common process is biological oxidation, where certain bacteria and fungi possess enzymes that can oxidize Cr (III) to Cr (VI). These microorganisms use the reduced form of organic matter or other electron donors to carry out the oxidation reaction. (Scott et al. 2001).

Another process involves the reaction of Cr (III) with strong oxidizing agents, such as certain forms of chlorine, hypochlorite, or permanganate, which are present in some natural environments. These oxidizing agents can directly convert Cr (III) to Cr (VI).

It's important to note that the transformation of Cr(III) to Cr(VI) in natural environments is generally a slow process and can be influenced by various factors, including pH, temperature, presence of organic matter, and the specific oxidizing agents present in the environment. (Scott et al. 2001).

However, it's always recommended to handle construction materials containing any form of chromium with appropriate precautions. This includes following established safety guidelines for handling construction materials, such as wearing protective gloves, masks, and goggles, and ensuring good ventilation during any cutting, grinding, or other activities that may generate dust. Additionally, it's crucial to adhere to local regulations and guidelines regarding the use and disposal of construction materials containing chromium compounds.

3 Methodology

This study used a quantitative research approach with an experimental research design.

3.1 Data acquisition

Tailings material used was collected from the UG2 Tailings Storage Facility of the Jubilee Mine located in the Northen Cape province of South Africa. One 50 kg sample was collected.

3.2 Sampling and sample preparation

The sample collected had some lumps which were pulverised manually with a roller. This is important to reduce the sample at the particle size of 7 micrometre. The whole sample was put into the spinning riffler machine. Sample preparation is crucial in obtaining accurate and reliable X-ray fluorescence (XRF) results due to its direct influence on the representativeness and homogeneity of the analyzed sample. Proper sample preparation ensures that the sample is in an optimal condition for analysis, minimizing potential errors and uncertainties in the XRF measurements. As noted by Johnson and Smith (2010), "sample preparation is a critical step in X-ray fluorescence (XRF) analysis, as the accuracy and precision of the measurement heavily depend on the representative nature of the sample." X-ray fluorescence (XRF) analyzes a small portion of a sample, and the results are assumed to represent the entire sample. If the sample is not properly mixed or homogenized, the analyzed portion may not be representative of the overall composition, leading to inaccurate results.

Spinning rifflers are tools commonly used in laboratories for the purpose of sample preparation and analysis. They are specifically designed for dividing bulk samples of granular materials into smaller representative portions. Inadequate sample homogeneity or particle size can lead to variations in element distribution and concentration, resulting in inaccurate measurements. This is emphasized by Aramendia et al. (2015), who highlight that "sample heterogeneity and particle size can significantly affect the results of X-ray fluorescence (XRF) analysis, as they can lead to poor representation of the sample composition and inconsistent measurements."

Spinning rifflers consist of a rotating drum or tube that contains a series of equally spaced compartments or cells. The sample to be divided is loaded into the drum, and as it rotates, the material is evenly distributed among the compartments.

Using spinning rifflers, helped obtain smaller, representative subsamples from a larger bulk sample, allowing analyses or tests without using the entire sample. This method improves efficiency, reduces the risk of sample contamination, and ensures accurate and reliable results in laboratory procedures.

Meticulous sample preparation is fundamental in achieving reliable X-ray fluorescence (XRF) results by ensuring sample representativeness, homogeneity, and minimizing contamination. It directly impacts the accuracy and precision of the analysis, making it an indispensable aspect of the analytical process. This process is important in analysing if the bricks standard regulations as far as health, environment and quality is concerned.

Figure 2 presents the tailings sample being poured into spinning riffler feeder and split into equal parts in the spinning riffler at the same time creating a homogeneous mix.

Figure 1 The sample get reduced equally and blended in the spinning riffler

Spinning Riffer is very important process in analysing the material we want to use for bricks. It is a process we use in the preparation of X-ray fluorescence (XRF). X-ray fluorescence (XRF) analyzes a small portion of a sample, and that is small sample representing the entire sample is obtained by this process. This process also helps in properly mixing or homogenizing the analyzed portion, emphasized by Aramendia and al. (2015).

3.3 Sample analysis

3.3.1 XRF and XRD preparation

X-ray fluorescence (XRF) and X-ray diffraction (XRD) are analytical techniques used in material science and mineralogy to determine the elemental composition and crystal structure of a sample, respectively.

The X-ray fluorescence (XRF) preparation start from the sample preparation or pulverisation. The sample was dried at 100 degrees Celsius for an hour to remove moisture.

The sample was weighted at 10g and mixed with 5g Sasol Wax. The homogeneous mix was placed in an aluminium cup and pressed at 25 tons. A total of 50 grams of the PGM sample was submitted for X-ray diffraction (XRD). The figure below has been taken at the laboratory, illustrates the mix and how outcome after completion. (G.H.E. Ndonga 2022).

Figure 2 Ten grams PGM sample mix with five grams Sasol and Pressed mix for XRF analysis

The prepared samples were put in the X-ray fluorescence (XRF) and X-ray diffraction (XRD) machine for analysis respectively.

Has mentioned above at the Chemical composition of the PGM tailing, showed that there was high concentration of Fe2O3 in about 31.19% followed by SiO2 with 28.49%, Cr2O3 with 15.07%, MgO with 9.50% and lastly Al2O3 with 7.82%.

More analysis and processing were done to the tailing for the purpose of, examining the viability of extracting Cr_2O_3 (chromite) as a by-product and to reduce Cr_2O_3 in the material (tailing).

A dense medium separation (DMS) method was applied with the use of the Shaking table. Analyzing chromite before handling it in the process of making bricks out of PGMs is essential for optimizing the extraction process, ensuring environmental responsibility, maintaining quality, ensuring safety, and complying with regulations. It helps to make the entire process more efficient, effective, and sustainable.

3.4 Dense medium separation—shaking table

The dense medium separation (DMS) is a mineral processing technique used to separate particles based on their specific density. It is particularly effective for separating minerals with different densities, such as ores containing valuable minerals and gangue materials. (Gupta and Yan 2006 p. 527).

The shaking table, also known as a shaking concentrator or gravity shaker table, is one of the devices commonly used for DMS. The shaking table consists of a flat, inclined surface that is continuously shaken in a back-and-forth motion. When the table is shaken, a combination of flowing water and the shaking action causes the particles to stratify based on their density (Gülsoy 2019).

The prepared material is evenly distributed onto the top of the shaking table deck. The deck is typically sloped longitudinally and transversely to encourage the material to flow in a controlled manner. As the table is shaken, the material stratifies based on its density. Heavier particles, such as valuable minerals, sink to the bottom and are collected in the lower part of the table, while lighter particles, such as gangue materials, are carried away by the flowing water and exit at the table's higher end. Figure 5 illustrates the process of using the shaking table for material separation.

Figure 3 demonstrates the result from the shaking table of the PGM tailings material. The clear water with dark materials in the bucket is the concentrate which is denser. The dirty water in the bucket are light materials identified as tailings. (Ndonga 2023).

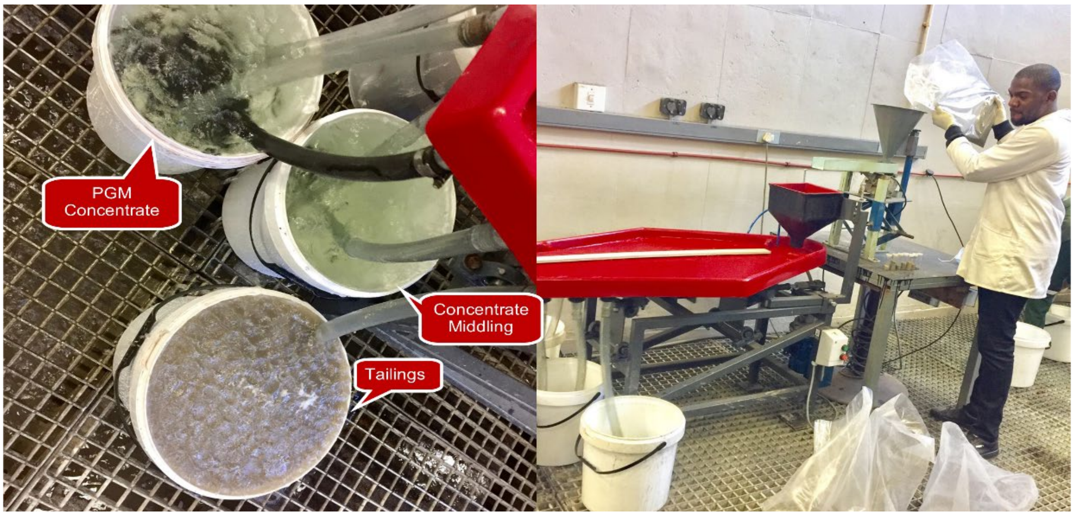

Figure 3 Concentrate and tailings from shaking table process

Both tailings and concentrate were left in water for a day for them to settle at the bottom of the bucket. Water was discharged and the materials were transferred to some plate to the oven to be dried. The oven was heated at 100 degrees Celsius. The dried tailings material was reduced in the spinning riffler and was further prepared of an X-ray fluorescence (XRF) analysis.

The importance of removing Cr2O3 in the material is to primarily reduce the present of the mineral in the material in order to prevent any form oxidation possible and to see the possibility of the Cr_2O_3 to be used as by-product for economic benefit.

3.5 Wet screening

To determine the particle size of chromite, a mineral deportment was conducted using the wet screening process. Wet screening is a common method used in various industries to separate solid particles based on their particle size. The sequential sieves size used was 75 µm, 53 µm and 38 µm which assisted to determine the particle size of high than 75 µm in other word (75+), (-75 and 53), (-53 and 38) and (-38). The wet material at each category was collected and dried in the oven at 100 degrees Celsius. Each sample was prepared for X-ray fluorescence (XRF) checking the chromite distribution in each particle size category. Based on the X-ray fluorescence (XRF) result, the chromite presence in the PGM sample was evenly distributed across all particle size category. Table 3, 4,5 and 6 summarises the X-ray fluorescence (XRF) results after wet screening.

Table 1 XRF analysis Result for 75+,53 and 38 particle size- wet screening

Component	Unit	Results %			
	mass%	75+	-75, +53	-53, +38	-38
Na2O		0.0849	0.0632	0.1528	0.1732
MgO		6.2117	7.1322	7.5437	11.0164
Al2O3		7.1430	8.6214	9.1705	9.0346
SiO2		30.4869	30.4859	29.7375	29.1899
P2O5		0.0248	0.0136	0.0207	0.0283
SO3		0.0907	0.1548	0.2004	0.2745
K2O		0.2296	0.1839	0.1508	0.1045
CaO		6.6597	6.1548	5.6752	4.9583
TiO2		0.6981	0.6874	0.7043	0.7173
V2O5		0.2437	0.2715	0.3195	0.2791
Cr2O3		12.2456	15.1787	16.7127	16.6987
MnO		0.4779	0.4163	0.3812	0.3546
Fe2O3		34.7535	30.0339	28.5708	26.4704
Co2O3		0.0742	0.0000	0.0535	0.0444
NiO		0.4359	0.3507	0.3573	0.3428
ZnO		0.1088	0.1921	0.2003	0.2106
SrO		0.0309	0.0287	0.0184	0.0177

3.6 Magnetic separation

In attempting to see if the Iron and Chromite can be further recovered as a byproduct but cost effectively and also to reduce chromite in the PGM sample, a magnetic separation method was used.

All the PGMs sample run through the magnetic machine, the MAG was run at 3.0 Ampere (Magnetic inducer), the ROLL on 44 volt and the feeder was run at 8 meter per second. The setup was done purposely to all a slow and effective separation of metals from the sample.

The Non-Magnetic sample at the inducer was collected on a direct bucket, and the same was applied to the Magnetic attractive sample.

After the magnectic separation samples where prepared for X-ray fluorescence (XRF) analysis and was analysed and the result shows that, the Non-Magnetic samples had less on Cr_2O_3 percentage ratio.

Table 2 summarises the X-ray fluorescence (XRF) results after the magnectic separation process.

Table 2 Non-magnetic sample XRF analysis

X-ray fluorescence (XRF) analysis result – non-magnetic sample					
Component	**Unit mass%**	**Results %**	**Component**	**Unit mass%**	**Results %**
Na2O	mass%	0.1480	V2O5	mass%	0.2026
MgO	mass%	6.8192	Cr2O3	mass%	9.8418
Al2O3	mass%	10.6362	MnO	mass%	0.3955
SiO2	mass%	34.9483	Fe2O3	mass%	26.3031
P2O5	mass%	0.0253	Co2O3	mass%	0.0451
SO3	mass%	0.1772	NiO	mass%	0.3286
K2O	mass%	0.2151	CuO	mass%	0.0310
CaO	mass%	9.0564	ZnO	mass%	0.1282
TiO2	mass%	0.6418	SrO	mass%	0.0566

After the magnetic separation process, the resuts shows that most of the chemicals was brought to less than 0.4%, chromite (III) was reduced to 9.84% mass. The whole sample add a great repretation of only, Al2O3, SiO2 CaO, Cr2O3 and Fe2O3.

4 Results

4.1 Chemical properties of PGM tailings

An X-Ray Fluorescence (XRF) analysis was conducted on the first sample collected the mine tailing.

The results show the proportion of oxides in the materials that are used for commercial brick and tails making. Based on the result Calcium and silica reactions with water will produce cementitious compounds. (Mashifana 2020). The result shows that there was high concentration of Fe2O3 in about 31.19% followed by SiO2 with 28.49%, Cr2O3 with 15.07%, MgO with 9.50% and lastly Al2O3 with 7.82%. Those constitute the main composition of the tailing.

4.2 Design mix

4.2.1 Tailings-to-bricks

The process started by analysing the PGMs tailings to determine their composition and physical properties. This analysis helped to identify the major components present in the tailings and any impurities that need to be addressed during the mixing.

Creating construction bricks from Platinum Group Metals (PGMs) tailings involved a complex and specialized process that typically required collaboration between mining, metallurgical and construction experts.

The design mix outline for transforming Platinum Group Metals (PGMs) tailings into construction bricks requires the following material:

1. Platinum Group Metals (PGMs) tailings (primary material)
2. Coal fly ash - to provide cohesion and strength.
3. Fine aggregates (sand) and small gravel - to improve workability and durability.

4. Water - for hydration of binding agent
5. Cement - to provide stability and strength.

PGMs tailings contained fine particles and potentially harmful substances, which if oxidized i.e. chromite Cr_2O_3 can cause health problems. To ensure stability and minimize environmental impact, it was important to add stabilizers such as cement, and fly ash. Stabilizers bonded the particles together and enhance the strength of the bricks.

The tailings acted as a fine aggregate in the mix, but additional coarse aggregates may be required to improve strength and workability. Common options included crushed gravel of small particles. The selection of coarse aggregate is optional, and should be based on regional availability, particle size distribution, and compatibility with the tailings since the research focuses on approaching this solution cost effectively.

4.2.2 Proportioning

The proportion of each component in the mix depends on the desired properties of the bricks. Generally, a mix design for construction bricks includes cement, water, tailings, and aggregates. The proportions will vary depending on the specific requirements, but a starting point could be:

- **Cement:** Typically, cement content ranged at 10% of the total mix.
- **Water:** 600ml to 700ml
- **Tailings:** 60% to 73.7% weight of the total mix. This was done purposely to utilise more Tailing for rehabilitation end goal.
- **Aggregates:** The coarse aggregate content was 20% by weight of the total mix, of the brick called Strength, to achieve the desired strength and workability.
- **Coal Fly Ash:** 25% to 35% by weight of the total mix.

The figure 4 shows the different material used, how it has been mixed and put in the Mold and how the brick looks after dried. (G.H.E. Ndonga 2023).

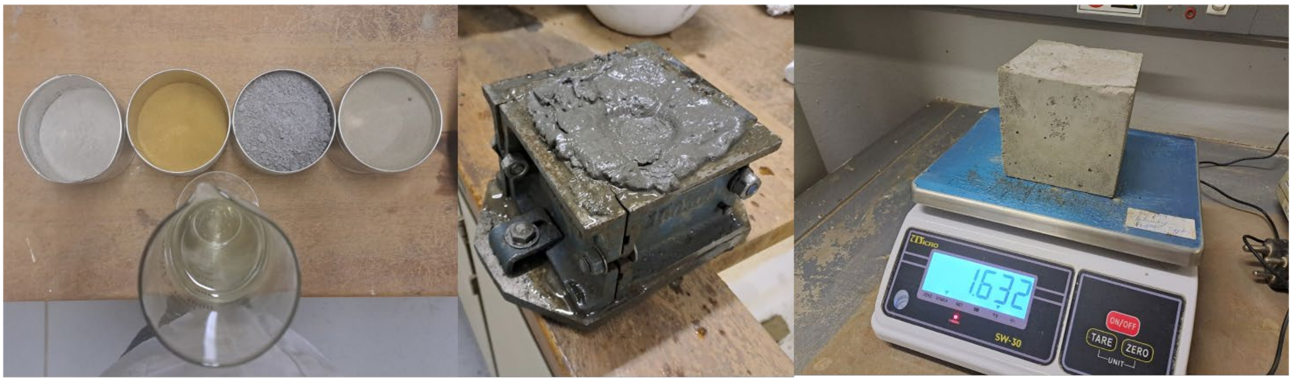

Figure 4 Material proportion mix, mold used for bricks and the brick outcome

A mold of 100 mm x 100 mm was used to bake the bricks, and bricks were dried in the oven at 100 degrees celsius.

4.2.3 Testing and optimization

The nine (9) bricks were prepared, the testing to assess the compressive strength, tensile strength, and water absorption as well as other relevant properties of the bricks are ongoing and will be published in the future.

Based on these test results any adjustments can be made to optimize the mix, such as modifying the proportions of cement, water, tailings, or aggregates.

It is crucial to note that the specific mix design may vary depending on the characteristics of the PGM tailings, regional availability of materials, and intended application of the bricks. This will involve adding more gravel, clay, and more cements if the region has great potential of these materials and can be acquired at a very low cost.

5 Discussion

5.1 Benefits of PGM tailings-to-bricks conversion

PGM tailings bricks can help reduce the environmental impact of mining activities by utilizing waste materials that would otherwise be discarded. This can lead to a decrease in the volume of mining waste and a potential reduction in the need for additional resource extraction, (Klinkenberg M. and Solozhenkin P.M. 2020). It helps in resource conservation. By using PGM tailings, these bricks contribute to the conservation of natural resources like clay and other materials typically used in conventional brick production, (Adhikary B. Mandal S. and Ghosh A. 2019).

Energy Efficiency: The production of conventional bricks from clay involves energy-intensive processes, such as firing in kilns. In contrast, PGM tailings bricks may require lower energy inputs during the manufacturing process, potentially leading to reduced greenhouse gas emissions. (Nzila C. Saidi M. and Ndungu P. 2018).

Reduced Carbon Footprint: Depending on the production process, PGM tailings bricks could potentially result in a lower carbon footprint due to reduced energy usage and decreased reliance on traditional raw materials. (Nzila C. Saidi M. and Ndungu P. 2018).

Innovative Application: The utilization of mining waste for construction purposes showcases innovation in materials science and resource management.

5.2 Waste reduction and environmental implications

Utilizing PGM tailings for brick production can help in reducing the environmental impact caused by the disposal of these mining residues. It can also prevent the contamination of soil and water system surrounding the mining areas.

5.3 Resource recovery and circular economy

Converting PGM tailings into bricks could offer several economic advantages namely:

Resource Recovery: Extracting PGMs from tailings for use in various industries can provide an additional revenue stream for mining companies. This diversification of income sources can contribute to financial stability and resilience.

Job Creation: The process of converting tailings into bricks would require a workforce with specialized skills, potentially leading to job creation and economic development in the local communities around the mining operations and in the country.

Brick Market: Bricks are essential construction materials with a strong demand in the construction industry. The bricks produced from PGM tailings could potentially find a market, generating revenue for both the mining companies and the local economy.

Sustainable Practices: Embracing sustainable practices and environmental stewardship can improve the reputation of mining companies, potentially attracting responsible investment and partnerships.

Social and economic contribution and responsibility of Mines to the community: Embracing this project will save the mines money and sustainably contribute to the social economic contribution to the communities which in south Africa is part of the governmental regulation or requirement for each mine. This involves and not exclusive of creating employment opportunities, Infrastructure development, Skills development and Training, tourism and cultural preservation and export earnings.

5.4 Economic viability and cost savings

The bricks production process using PGM tailings is viable, it could generate economic benefits by monetizing the waste product that would otherwise require costly storage and management to both the government and mining companies. This project will help develop the infrastructures, boosting the economy and save the mines a significant amount of money that is already spent on Tailings Facility Construction and Maintenance, Safety Measures of dams, Remediation and Site Closure, Water Management, Environmental Monitoring and Reporting, Regulatory Compliance, high Liabilities and Insurance, Research, and Innovation. The cost breakdown and project cost will be highlighted in the second volume of this paper.

A tailing dams failure recorded causing more than 1 million cubic meters of tailings resulting to loss of life cost in average USD 543 million per failure. (Chamber 2015).

A manufacturing plant for bricks and processing building materials will be needed at a central area of the tailing dams, where available water resources is present. The brick manufacturing plant will involve several key processes, including raw material preparation, moulding, drying, firing, and quality control (Smith 2020). The manufacturing plant will have two main operations:

- Making Bricks for various purposes, using at best the tailing waste
- Packaging the ready-mix solution for bricks making into 50 Kg bags that will be for sale. The 50 kg bag will consist of the PGM tailing solution for bricks making, where the end-user will have to just add water to make bricks based on the provided usage guidelines.

The cost of these manufacturing plants will come from a join venture of mines using a portion of their tailing maintenance, management, and other associated mine closure and funds relating to waste, that are monthly put into the trust funds.

5.5 Sustainable construction materials

The government and Mining companies that generate PGM tailings and Coal fly Ash can collaborate with us to explore the feasibility of using these tailings as a raw material establishing a structure to make bricks and develop infrastructures that will benefit the communities and the country at large. This projects and be implemented anywhere in the world provided.

In regions where housing is scarce, tailings bricks could be utilized to construct affordable and sustainable housing solutions for communities. Tailings bricks can be used as a sustainable alternative to traditional clay bricks in various construction projects, such as building homes, schools, and commercial structures. PGM tailings bricks can be employed in road construction to provide a durable and environmentally friendly road surface. Tailings bricks can be used for landscaping features like garden paths, patios, and decorative elements in parks and public spaces.

6 Conclusion

This study shed light on the potential of transforming PGM tailings into construction bricks as a sustainable approach to waste management and resource recovery. By considering the composition and characteristics of PGM tailings, the challenges of traditional tailings management methods, and the benefits of tailings to bricks conversion, this study presents a comprehensive analysis of the feasibility and implications of this innovative waste utilization strategy. Through successful case studies and pilot projects, this research demonstrates the technical and economic viability of the process and identifies key considerations for future implementation. Ultimately, the integration of PGM tailings into construction bricks has the potential to promote a circular economy, reduce environmental impact, and contribute to the sustainable development of the mining industry. More research and tests are ongoing and the results will be published in the future.

7 Recommendations for further research and implementation

Before implementing PGM Tailings Brick Productions, it's essential to conduct thorough testing and research to ensure that the bricks meet required all quality standards and safety regulations. Additionally, collaborating with governmental authorities, mining companies and funding organisation and stakeholder is crucial to gaining support and addressing any potential concerns.

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