International Journal of Advances in Scientific Research and Engineering (ijasre)

E-ISSN : 2454-8006

DOI: [10.31695/IJASRE.2022.8.3.3](https://doi.org/10.31695/IJASRE.2022.8.3.3)

Volume 8, Issue 3
March - 2022

Determination of Minerals of Cassiterite Tailings and its Recycling Potential Using Empirical Method at Plateau State Nigeria

Akinola Abayomi Paul[1], Abinya Obams[2] and Achuenu Ifeanyi[3]

[1] Lecturer, [2] Student and [3] Technologist,

Department of Mining Engineering

University of Jos, Nigeria

ABSTRACT

The mineral potential of cassiterite fines from tailing dumps in the Jos Tin Mining Community Resource Centre (MCRC), Plateau State Nigeria, were studied through a wet concentration process and dry electrostatic and magnetic processes and then evaluated using empirical evidence. Three samples of the tailing dumps with the size of mineral smaller than 5 mm were collected at random through the "Tin Mining Community Resource Centre". The huge pile of the tailing dumps may have an environmental impact in the area, so they need to be treated and recovered for the valuable heavy minerals and sand tailing for the local construction industry. The grade of the average tailing dumps as analyzed using XRF were 2.08% Sn, 3.51% Nb, 25.5% Fe, 14.91%Ti, 8.36% Zr, 12.99% Al, and 45.68% Si. The percentage compositions of the cassiterite tailings were expressed to its simplest genetic mineral forms using an empirical formula. The genetic mineral forms were ilmenite, zircon and sand. Since ilmenite has the highest concentration in the cassiterite tailings and the highest economic values, then recycling of ilmenite should be ascertained. After the wet processing by the screen, hydro cyclone, spiral concentrator, and shaking table, the concentrate consists the most of, ilmenite, zircon, and sand. The following dry processes used rotary dryer, screening, electrostatic separator, magnetic separator to separate cassiterite from the heavy minerals and sand. The final iron and titanium concentrate can be upgraded to 72% Fe and Ti using certain reagents such as fluoride acids which can be sold to the Iron ore smelting plant.

Keywords: Cassiterite, Tailing, Ilmenite, Empirical, MCRC.

1.0. INTRODUCTION

Over the years, about 50years ago, there has been mineral processing of cassiterite in Jos Tin Mining Community Resource Centre (MCRC), with the sole aim of liberating Tin from the cassiterite, but little or no attention has been paid to the associated minerals with conception that the associated minerals are considered waste or gangue minerals. In recent years, the properties of the elements of these associated minerals become more valuable than even the Tin itself in the extractive industries of the World. This research is aimed at studying the minerals of cassiterite tailings and its recycling potential using an empirical evidence, as well as to assess the economic value of the minerals with respect to their properties. Assessment of minerals of Jos Tin Mining Community Resource Centre (MCRC) using XRF and empirical calculation show that ore tailings consists of Ilmenite, Zircon, and Sand. But because of their economic values in the extractive industry, the tailings should be recycled.

More importantly, the type of iron ore in the tailings as revealed by empirical evidence is Ilmenite. Based on these analyses, the cassiterite tailings of Jos Tin MCRC has a high recycling potential.

The concentration of minerals and its economic value in mine tailings give the recycling potential of mine tailings. XRF analysis reveals the chemical composition of the mine tailings and then converts them to the real genetic minerals using empirical formula according to Achuenu, Abayomi and Joro (2021). The genetic minerals obtained using empirical evidence are the mineral potential of the mine tailings and their economic value give the recycling value of the mine tailings. Most of Tin and other associated minerals such as Ilmenite, Magnetite, Ulvospinel, Haematite and Zircon, found in Jos Plateau state are in the form of cassiterite (SnO_2). The occurrence of cassiterite is normally related to Jos-Bukuru Younger Granite and Biotite Granite, formation extending from the north to the south of Jos. There are two types of accumulation of cassiterite found in Jos and they are in the form of primary and secondary types. The primary formation of tin is of hard rock type without weathering from the source rock while the secondary one is of weathered rock type, either in situ or some are transported from the source rock by stream or river, to form the alluvial deposit of tin and other associated heavy minerals. Tin deposit is commonly mined by gravel pump (or is some cases by hydraulic) mining as this mining method is cheaper to recovery tin. Primary concentrate: It has been briefly mentioned earlier that the multi-lane palong-jigs system is popularly adopted by gravel-pump miners for primary concentration of cassiterite. The set-up is logical, because it is capable of coping with a high volume of ground slurry (≈ 3,000 gallons per minute at 5 - 10 percent solids) and could maintain a high level of recovery of cassiterite, the result being confirmed by the absence of dulang washers who would usually wash for tin ore in the tailing discharged. Several studies were conducted to improve the cassiterite to use in the industries in many countries

After the processing of valuable minerals from ores minerals, mining operation leaves a tremendous amount of tailings that may exist as a legacy at the site requiring considerable long-term attention. Cu mineral (CuO, Cu_2FeO) as an example, typically contain 0.5% to 2% copper as mineral and produce a concentrate grade varying from 25% to 45% Cu, meaning that from 93% to 99% of these ores are rejected as tailings (Vogt, 2012). The chemistry features are determined primarily by ore mineralogy, processing methods, and treatment before disposal.

The disposal of mine mill tailings in mineral processing plants is a controversial and frequently objects of discussion that becomes especially radical when accident occurs (Fiqueiredo, 2018). The dynamic changes in the chemical composition, as well as the alteration of the structural equilibrium of these tailings due to the progressive erosion caused by rainfall, dispersion by wind and potentially human activities is of great concerned (Fiuza, 2018). Many of these mine tailings being disposed may contain valuable metals with substantial economic value in the modern mineral market. The tailings may contain metals that were not of economic interest at the time when the mining operation and processing occurred and are in demand nowadays (Eit, 2017). Sometimes, the grades of these tailings are exploitable by reprocessing or direct use. As a result, ascertaining the recycling potential of the tailings and their utilization will be considered in this research study. Mine mill tailings in Mining Community Resource Center (MCRC), Jos of Plateau State, Nigeria will be ascertained in this project for potential recycling and utilization.

1.2. STATEMENT OF PROJECT RESEARCH

The generation and disposal of mine tailings from mine mills are capable of causing both internal and external environmental pollution or accident and therefore, the need to properly manage and recycle these tailings for potential utilization will go a long way in minimizing these negatives impact or effects on the environment and at the same time generating wealth for the industries concerned and preserving other form of raw materials for future utility.

1.3. JUSTIFICATION OF RESEARCH

Recycling is a process that involves the conversion of mine tailings materials into meaningful usage. It is an alternative to “conventional” tailings disposal that can save material and prevent environmental pollution. Recycling these mineral tailings can prevent environmental hazard and reduce the consumption of fresh raw materials. This ensures no space for waste, reduce financial expenditure in the economy of the mine industry, and preserve natural resources for future generation.

1.4. AIM OF THE STUDY

The main aim of this research study is to evaluate the minerals of cassiterite mine tailings in which the chemical compositions are expressed to its simplest mineral form using empirical formula, so that the recycling potential and utilization of Mine mill tailings are ascertained.

1.5. OBJECTIVES OF THE STUDY

The objectives of this research study are to:

1. Collect mine tailings,
2. Analyze mine tailings and,
3. Determine the chemical composition using X-ray fluorescence.
4. Express the mineral composition into its empirical formula

1.6. SCOPE OF RESEARCH

DOI: 10.31695/IJASRE.2022.8.3.3

The scope of this research study is limited to ascertaining the recycling potential and utilization of mine mill tailings of mine processing plant located at Mining Resources Community Center (MCRC), Kashim Ibrahim Street, West of Mines, Jos Plateau State Nigeria.

1.7. RESEARCH QUESTIONS

1. What are the chemical compositions of these mine mill tailings?
2. Do these mine tailings have recycling potential?
3. What are the genetic minerals of the cassiterite of MCRC

1.8. LOCATION OF STYDY AREA

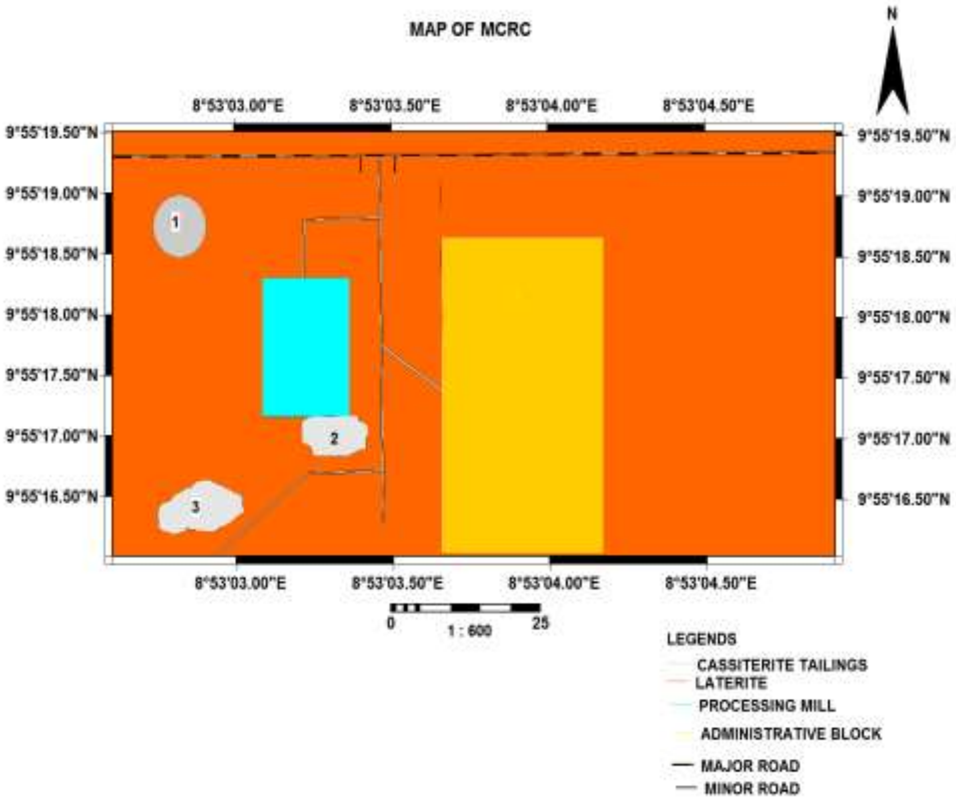


Figure1: Location of study area

2. LITERATURE REVIEW

2.1 INTRODUCTION

Das *et al* (2000) described a sustainable way of handling iron ore tailings by converting them into a new value added product as ceramic floor and wall tiles for building applications. The iron ore tailings were found to contain high percentage of silica and they concluded that iron ore tailings up to 40% by weight can be considered for use as a part of raw materials for ceramic floor and wall tiles due to its high silica content. The ceramic tiles from the iron ore tailings were found to be superior in terms of scratch hardness and strength. The new tiles from the iron ore tailings also maintain most of the other essential properties as the conventional raw materials of ceramic tiles. The application of iron ore tailings in the ceramic tiles production was cost effective in comparison with the usual traditional clay for ceramic tiles production. (Zhang, 2012) also confirmed that it is possible to make eco-friendly bricks using geo-polymerization technology by selecting appropriate preparation conditions.

Recycling of mine tailings from dump site have been shown to be an effective method to deal with tailings especially when one considers the significant improvements in modern processing technology and the increase in metal prices. These have the potential to generate considerable profit. The idea is to mine and re-process old tailings from tailings dump site to extract valuable minerals for utilization while minimizing the environmental impact caused by these tailings. Some tailings can be regarded as a potential ore body with considerable metal value. For example, Amerigo Resources are processing tailings from

DOI: 10.31695/IJASRE.2022.8.3.3

Codelco'sElTeniente mine in Chile, the largest underground copper mine in the world (Williams, 2009). The limitations of past mineral processing technology mean that considerable amounts of valuable minerals were often lost to the tailings. Furthermore, the rising copper price is encouraged companies to consider retreatment and recycling of mine tailings, enabling them to turn a waste into a value (ANON, 2004). Recycling and utilization of Mine Tailings depends on many factors including:

1. The chemical composition of the tailings materials.
2. The specific lifetime of the tailings materials from time of deposition.
3. Storage facilities.
4. Effects of the mine mill tailings.
5. Elemental composition of these tailings.
6. Economic benefits.
7. Mineralogical composition etc.

One of the advantages of tailing recycling is that the mining of tailings do not require creating a new underground mine or open pit with the associated blasting and material transportation systems. Instead hydraulic mining with high pressure water hoses and simple ditches or launders can be used to transport the "ore" to the new processing facility and significant capital and operation costs savings will ensue. In addition, with an already finely-ground constitution, the energy costs of processing tailings will be significantly lower due to a reduction in grinding requirements. Recycling may also present an opportunity to cut down long-term mine closure costs by eliminating the need for a water treatment plant (WTP) for effluent currently leaving the site after passing through the existing dam. As a reclamation strategy, retreatment is not only aimed at recovering valuable minerals. It is also an opportunity to reduce the liability of storing tailings on surface in-perpetuity.

Utilization refers to the economic importance, usage or consumption of the tailings products before or after reprocessing. Sometimes, recycling of these mine mill tailings and its utilization might not be the problem many mine industries who engage in tailings production or generation are facing despite the fact that there is much more desirable minerals concentrate left in the tailings but the fear of its effect as a result of the presence of undesirable harmful chemicals or mineral unknown to them. Due to these fears, it is important to ascertain the recycling potential of these mine tailings through chemical analysis before proceeding recycling for utilization. The word “Recycling” could connote a lot of meaning such as “to pass again through a series of changes or treatment”, “to reprocess a solid waste or liquid waste” in order to regain valuable materials for human use through biological activities and through naturals processes of biochemical degradation or modification, to adapt to a new use (Encyclopedia, 2019). According to Britannica, (2019), recycling of mine mill Tailings involves the recovery, reprocessing of mine tailings materials for use in new products. The basic phase in recycling mine mill tailings are the collection of tailing samples in desired locations of interest, carrying out chemical analysis to ascertain and reprocessing or manufacturing them into new products for utilization..

2.2. CHARACTERISTIC OF MINE MILL TAILINGS

Mine tailings characteristics can vary greatly and are dependent on the ore mineralogy together with the physical and chemical processes used to extract the economic products at the time of initial processing. (Ritcey, 1989) reported that mine tailings of the same type may possess different mineralogy and therefore will have different physical and chemical characteristics. Mine tailings characteristics need to be ascertained to establish the behavior of the tailings ones deposited in their final storage location and the potential short and long term liabilities and environmental impacts. Once the likely characteristic of the tailings are ascertained, examined through chemical laboratory analysis and pilot plants test then, the necessary recycling of these tailings can be identified and carried out for effective utilization. Also from this, the necessary design requirement can be identified to mitigate environmental impact as well as determine optimum operational performance (ANON, 2004). To help determine the design requirements of a tailings storage facility and, the following characteristics of the tailings will need to be established (ANON, 2004). This characteristic also affects the chances of recycling and utilization of mine tailings. They include:

1. Chemical Composition (including changes in chemistry through mineral processing) and its ability to oxidize and mobilize metals.
2. Physical composition and stability (static and seismic loading).
3. Behavior under pressure and consolidation rates.
4. Erosion stability (wind and water).
5. Settling, drying time and densification behavior after deposition.
6. Hard pan behavior (e.g. crust formation on top of the tailings).

2.3. COMPOSITION OF MINE MILL TAILINGS

DOI: 10.31695/IJASRE.2022.8.3.3

Mine tailings size and composition depend on the mining and processing method. For hard rock's metals mines, tailings are usually a very fine mud or powder which is left over after ore is crushed and valuable minerals known as the concentrate are extracted from it. Tailings may also contain chemicals used for mineral concentrate extraction. It may contain residual metals such as Iron, Copper, Nickel, Zinc and other valuable minerals in relatively high concentration (from 0.5 to 3% or so) and occasionally the presence of precious metals such as gold, silver and many others. Although the metals contents is removed in the metallurgic process, some ore sulfides (e.g. pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, etc.) can be deposited, either because they were not sufficiently high grade for use, or due to a deficient extraction technology. They entail both an accumulation and a potential emission source of trace elements (e.g., Cu, Fe, Pb, and Zn). Oxidation of the sulfide minerals accumulated in the abandoned mine tailings may cause (Ortiz and Martin, 2019):

1. Highly contaminating acid mine drainage (AMD) from leakages.
2. Mobilization of significant quantities of trace elements such as As, Cd, Cu, Hg, and Pb. It then becomes necessary to characterize these hazardous mine tailings areas where large quantities of potentially toxic elements can be released into the environment and possibly undergoing a recycling program on them. (Crespo and Gomez, 2019).

2.4. NATURE OF MINE TAILINGS

The processes of beneficiation of run of the mine ores and subsequent disposal to surface containment facilities expose elements to accelerated weathering and can consequently increase their mobilization rates. The addition of chemical reagents used in mineral processing may also change the chemical characteristics of the processed minerals and therefore the properties of the tailings and waste rock (Daniel and Downing, 2004). The extraction and processing of hard rock sulphidic bearing ores is just one example of accelerated weathering. In this case, the sulphide minerals more readily oxidize in the tailings facility as a result of the size reduction from milling increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilization occurs and can find their way into the surrounding environment through runoff or seepage and leakages. This phenomenon is a well-known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) (Garcia and Ballester *et al.* 2005); (Ritcey, 2005). Depending on the mining project that is to be embark, alternative tailings storage techniques such as sub-aqueous disposal (below water deposition), and high density thickened tailings or dry stacking can be implemented to control oxidation of sulphides and the mobilization of metals.

2.5. GENERATION OF MINE TAILINGS

The generation and disposal of tailings is commonly identified as the single most important source of environmental impact for many mining operations in countries of concern (Vick, 1990). This is not at all surprising when considering that the volume of tailings requiring storage can often exceed the in-situ total volume of the ore being mined and processed. Over the last few centuries, the volumes of tailings being generated by processes mill has grown dramatically as the demand for minerals and metals has increased and lower grades of ore are being mined due to advances in extraction and processing technology. In the 1960's, 10's of thousands of tonnes of tailings were produced each day and by 2000 this figure had increased to 100's of thousands (Jakubick and McKenna *et al.* 2003). Today and in countries such as Nigeria, there are individual mines in the country producing in excess of 200,000 tonnes of tailings per day. Understanding the mineral processing techniques can help to determine how these tailings are produced and the challenges associated with their storage and the possibility of recycling.

Run of the mine ores are physically reduced by natural phenomena or through crushing and grinding methods, using the likes of Cone Crusher, Pulverizer, etc. The optimum degree of grinding is determined by the extraction methods used to remove the economic product. A simple mineralogical examination can hold the key to identifying the most advantageous extraction methods to use. The examination can also determine other minerals of economic interest, the type and quantities of reagents required to separate the concentrate from the gangue materials and the necessary storage methods for the tailings (Ritcey, 1989). Pilot plant tests can also be useful to determine optimum particle size, processing reagents required and the final tailings characteristics and composition. However, such pilot tests may not be an exact representative of the tailings that will be produced from the full scale plant. This means that the final design of any tailings facility is always provisional and must be confirmed once tailings production is underway (Blight, 1998).

Froth flotation is the most widely used concentration method and is normally the first step in the mineral processing sequence where chemical reagents are introduced (Vick, 1990). Gravity and magnetic separation are also some of the techniques that are employed and used to win the economic product from the ground ore. Gravity separation is used in gold processing to recover the coarser particles, the finer being recovered by leaching (Daniel and Downing, 2004). Refractory ores are commonly processed using pressure oxidation, bioleaching and roasting prior to leaching techniques. These types of pre-processing are often associated with ultra-fine grinding that generates tailings with slow settling and low in-situ density properties. The five basic types of reagent used in froth flotation recovery include Collectors, Frothers, Depressants, Activators and Modifiers. When designing the processing plant, the types and quantities of reagents used should be considered together with any depressing requirements to lessen environmental impacts in the tailings streams (Ritcey, 1989). Reagents dosed in small quantities are either consumed,

DOI: 10.31695/IJASRE.2022.8.3.3

retained in the process or are discharged with the tailings. The design of a tailings storage facility should therefore be optimized to prevent weathering and the mobilization of contaminants, whilst also increase the degradation rates of reagents stored in the tailings facility.

2.6. EFFECTS/ HAZARDOUS PROPERTIES OF MINE TAILINGS

Toxic chemicals used to extract the valuable minerals (i.e. concentrate) from the ore such as the cyanide, mercury used in gold mining, remain in the tailings at the end of the process and may leach out into the environment and ground water. Rocks naturally may contain dangerous and hazardous chemicals such as arsenic, lead, wolframite etc., which may be leach into water bodies and the environs and as a result, acid mine drainage (AMD) is the most frequent and widespread problem. The result of these can be the production of very acidic water which additionally leaches metals and other hazardous chemicals from the surrounding rocks. Also, the presence of pyrite that oxidizes upon exposure to the atmosphere results in acid generation. Since pyrite and other potential elements was not recovered as a mineral of economic value during mining, they are disposed off in tailings ponds and in other forms of tailings storage methods that are now a source of acid generation and released of metals to the environment (Pulford, 1991). If these mine tailings are not ascertained for harmful elements before recycling, their recycling might also be a platform of spreading these harmful elements to the environments and society at large.

2.7. TYPES OF MINE MILL TAILINGS

Mine mill tailings which are the residues materials left over after separating the valuable (concentrates) metals or minerals from an ores are of the following types (Kuipers and PE, 2015).

1. **Gravity Processing Tailings:** These are tailings originating from the gravity concentration of minerals in processing plants. It includes the tailings from the gravity concentration of gold ore etc.
2. **Flotation Process Tailings:** These tailings generation are obtained from the floatation action of mine ores during ore processing using water. These tailings either settle at the bottom of the used container or are seen floating on top of the water in which they are later collected and stored as tailings after the desired concentrate as of that time is extracted in the process.
3. **Leach Process Tailing:** An industrial mining process used to extract precious metals copper, uranium, nickel and other compounds from ore using a series of chemical reactions that absorb specific minerals and re-separate them after their division from other earth materials
4. **Bayer process tailings:** Bauxite tailings are generated from industrial production of alumina (aluminium oxide, the principal raw material used in the manufacture of aluminium metal. Over 95% of the alumina produced globally is through the Bayer process; for every tonnes of alumina produced; approximately 1 to 1.5 tonnes of bauxite tailings/residue are also produced. Annual production of alumina in 2018 was approximately 126 million tonnes resulting in the generation of over 160 million tonnes of bauxite tailings/residue (World Aluminium, 2019).
5. These also include others, but not limited to tailings from Copper, Iron, Lead, Rare Earth, Phosphate, and Platinum, Silver, Uranium, Zinc and Cassiterite tailings etc.

2.8. TAILINGS STORAGE AND MANAGEMENTS

Mine Tailings are usually stored in different forms and are usually stored in the most cost effective way possible to meet regulations and site specific factors. The process of mineral extraction is never 100% efficient nor is it possible to reclaim all reusable and expended processing reagents and chemicals. The unrecoverable and uneconomic metals, minerals, chemical, organics and process water (as of that time of operations) are discharged normally as slurry and could sometimes as dry tailings depending on the processed method used to a final storage area commonly known as a tailings management facility (TMF), or tailings storage facility (TSF) (Engels, 2002). The majority of historical tailings related incidents have been influenced by poor day to day management which has resulted in the strengthening of regulations controlling tailings storage today. Tailings can be disposed of using a variety of methods. Selection of a disposal method is a complex issue which depends on local geography and hydrology as well as the nature of the tailings.

1. **Tailings Dams and Ponds:** Surface impoundment of tailings is the most widely used disposal method around the world. Embankment for surface disposal can be classified into two types: Water-retention and Raised embankments (Vick, 1983). While this type of construction is the best one from a long-term safety viewpoint, it is by far the most costly and is rarely used as a tailings storage facility. (Mular, Halbe, and Barratt, 2002).
2. **Dry Stacking:** Tailings do not have to be stored in ponds or sent as slurries into oceans, rivers or streams. There is a growing use of the practice of dewatering tailings using vacuum or pressure filters so the tailings can then be stacked (Davies and M.P, 2001). This saves water which potentially reduces the impacts on the environment in terms of a

DOI: 10.31695/IJASRE.2022.8.3.3

reduction in the potential seepage rates; space used, leaves the tailings in a dense and stable arrangement and eliminates the long term liability that pods leave after mining is finished.

3. **Storage in Underground Workings:** In addition to surface disposal methods, underground disposal is also in wide-use. The main aim of returning tailings back into the mine is to support the mining operation underground and/or to maximize ore recovery rather than depositing tailings to reduce environmental impact (Vick, 1983). However, with advent of high-density paste backfill and agglomerated tailings paste (ATPF), all tailings can be stored in underground work or open pit space. Paste backfill uses unclassified tailings (with or without binder depending on fill strength requirements) at a pulp density of 72%-85% solids.
4. **Sub Marine Disposal:** Besides being stored on land, tailings can be deposited directly into nearby natural bodies of water, such as the ocean, a lake, or river Sub-marine disposal. (STD) or deep sea tailings placement (DSTP) is an significant underwater tailings placement alternative which has been used around the world at several mines in British Columbia the Philippines and central American (Vick, 1983) .the application of STD /DSTP is limited to mine located reasonably close (within 200 km) to a marine coast with deep water (100m) or to alpine lake with low aquatic life. It's perhaps the most controversial of the other methods.

2.9. PRIMARY ISSUES WITH OPERATING TAILINGS FACILITIES

The primary issues that tailings management and operation of facilities often encountered includes:

1. **Tailings storage design:** Critical features to consider in locating and designing mine tailings facilities includes; Hydrology, Hydrogeology, Geotechnical (density, strength, compaction, consolidation, rheology), Geochemical (Acid drainage, neutral and saline drainage, chemical influenced drainage), Construction and operation, Designing for recycling, utilization and closure, Tailings facility hazard ranking, other consideration (climate, terrain, use of open pit, return water facilities).
2. Tailings seepage (infiltration, through-flow, and ex-filtration of water into, though, and from tailings).
3. Tailing dust.
4. Long- term liability (release of contaminants to underground, release of contaminants and tailings to surface water, dust prevention, institutional controls, maintenance requirements).
5. Catastrophic features
6. Tailings chemical composition and tailings characteristics
7. Tailings utilization and possible future recycling (ANON, 2019)

2.10. BENEFITS OF MINE TAILINGS

In a world where we are faced with waste of natural resources, overflowing landfills, mining tailings and plastic in our oceans, recycling has become almost second nature. Recycling may have become a way of life but why exactly do we recycles mine tailings? What are the benefits of recycling mine mill tailings, specifically?

Recycling of mine mill tailings is not just good for the environment – it's essential. Recycling is one of the most effective ways to protect and conserved the natural world we live in by reprocessing and reusing mine recycles tailings and other form of old materials, we save the energy it would have taken to create new ones (ANON, 2019).

1. Recycling preserve the world natural resources: The world natural resources are finite and as result recycling preserves valuable natural resources for the good and longevity of the planets. It ensues we can continue to live the way we are accustomed to without environmental concern generated from fresh mining,
2. Protect the world's people: In the search for new mineral materials, it is often the poorest and most vulnerable people who end up being displaced from their homes. Communities living around mineral deposit area can find themselves evicted in the search for these potential minerals giving rise to the need for recycling.
3. Recycling of metal tailings means there is less need for expensive, dangerous and harmful extraction of new materials which will be time, money and energy consuming.
4. Making products from recycled materials requires less energy than creating them from raw materials and sometimes, the difference is immense, for example, producing aluminum from recycled cans and foil uses 95% less energy than starting from scratch.
5. Create Jobs: Recycling has created a wealth of new Jobs in the recycling industry itself and also in manufacturing companies and construction sector.
6. Tailings can be converted into building materials and use in mine backfills.
7. Recycling of mine mill tailings help to leave behind only clean water, rehabilitated landscapes and healthy ecosystems which are expected globally.

DOI: 10.31695/IJASRE.2022.8.3.3

8. Recycling mine mill tailings create more sustainable by-products to the company or industry. These includes everything from commercial shotcrete and concrete products to self-sustaining uses such as mine roads, bricks and tiles manufacturer, insulation or even foamed products.
9. By utilizing mine mill tailings as materials with value, as opposed to waste rocks, customers are able to extract treasure from trash; reducing the need for a whole new mine site to mine those minerals.

2.11. UTILZATION AND RECYCLING OPTIONS FOR MINE TAILINGS

Most mine tailings are difficult to utilize due to its finer grain size and harmful elements it contained, but can be utilized in selective operations. Based on the type of tailings pond, the water can be drained so that the remaining waste can be dried. The main condition of mine tailing utilization is that the materials should satisfy all the geotechnical criteria and is environmental friendly. A thorough characterization of mine tailings is essential as it must not be a source of contamination. The value of utilization of mine tailings can be enhanced on the basis of geotechnical properties and environmental constraints. Thus, uses of mine mill tailings include:

a) Mine mill tailings are used for the construction of mine roads possibly to mine site and out of mine site.
b) Mine mill tailings are used for foam products
c) Mine mill tailings (sand-rich) mixed with cement are used as a backfill in underground workings to provide ground and wall support supports, improved ventilation (Zhu, L.P, and Ni, 2011)
d) Mine mill tailings are used for concrete aggregate (silica, calcium oxide etc.).
e) Reprocessing of mine mill tailings to extract minerals and metals such as tin, tantalite, iron, Columbite, lead, monazite etc.
f) Waste reduction through targeted extraction of valuable minerals during processing
g) Clay-rich tailings as an amendment to sandy soils and for the manufacturing of bricks, cement, floor tiles, sanitary ware and porcelains.
h) Mn-rich mining tailings used in agro-forestry, building and construction materials, coatings, cast resin products, glass, ceramics and glazes (Silva, and Araujo, 2014).
i) Bauxite mine tailings are used as sources of alum, use also in building panels, bricks, foamed insulating bricks, tiles, gravel/railway ballest, calcium and silicon fertilizer, site restoration, scandium recovery, oil drilling, pigments, foamed glass, gas extraction, filler for PVC, wood substitute, arsenic removal, chromium removal, etc., (B. K., Parekh and Goldberger, 2019)
j) Cu-rich mine tailings used as extenders for paints (Sirkeci, and Gul, 2006)
k) Fe-rich mine tailings could be mixed with fly ash and sewage sludge as lightweight ceramics.
l) Energy recovery from compost-coal tailings mixtures.
m) Phlogopite-rich (brown to red form of mica) mine tailings for sewage treatment.
n) Phosphate-rich mine tailings for the extraction of phosphoric acid.
o) Ultramafic mine tailings for the production of glass and rock wool.
p) Carbon dioxide sequestration in ultramafic tailings and waste rocks.

2.12. CASSETERITE TAILINGS

Cassiterite (SnO_2) is a mineral ore that contains tin (Sn) about 57.82 wt. % and impurities like quartz, ilmenite, monazite, rutile and zircon etc.

Plate 2: MCRC Cassiterite tailings

DOI: 10.31695/IJASRE.2022.8.3.3

The initial step for the process involve the remove of impurities in Cassiterite through washing and separation by a high magnetic separator (HTS) (Manaf, Andryah, and laisam, 2019).Cassiterite is a tin oxide mineral with a chemical composition of SnO_2. It is the most important source of tin, and most of the world's supply of tin is obtained by mining Cassiterite. Small amounts of primary Cassiterite are found in igneous and metamorphic rocks throughout the world. It is also a residual mineral found in soils and sediments. Cassiterite is more resistant to weathering than many other minerals, and that causes it to be concentrated in stream and shoreline sediments. Although Cassiterite is the most important ore of tin, it has only been found in minable concentrations in a few locations. It is colorless when pure, but brown or black when iron impurities are present. Commercially important quantities occur in placer deposits, but Cassiterite also occurs in granite and pegmatite (Encyclopedia, 2015)

2.13. PHYSICAL CHARACTERISTIC OF CASSITERITE

Cassiterite has several properties that aid in its identification and enable it to be found in minable quantities. Its adamantine luster, high hardness (6 to 7), light streak, and high specific gravity (6.8 to 7.1) are helpful in its identification. Its high specific gravity, resistance to weathering and physical durability enables it to survive stream transport and concentrate in placer deposits (King, 2019). Primary deposits of Cassiterite worth mining are almost always found in high-temperature hydrothermal veins that accompany granitic intrusions. Cassiterite can be associated with Tourmaline, Topaz, Fluorite, and Apatite, Iron, Columbite, Silica, Fluorite, Apatite, Calcite, Schorl, Arsenopyrite, Limonite, Hedenbergite, Wolframite, Molybdenite, Tourmaline, Topaz, (King, 2019).

2.14. CASSITERITE DEPOSITS IN NIGERIA

Table1: Cassiterite Deposits in Nigeria

S/N	STATS	LOCATION
1	Cross River	Akaibamu, Ogoja, Obeju
2	Ekiti	Ijero
3	Nassarawa	Wamba
4	Kaduna	Kaduna, Jama'a
5	Plateau	Jos North/South
		Bakin-Ladi
		Bassa, Panshin
6	Kogi	Ojuwa – Olijo, Egbe
7 **8**	Adamawa Gombe	Toungu, Vere Hill Kaltun

Source: (Gibson, 2002)

3.0 METHODOLOGY

3.1. RESEARCH MATERIALS

Material used for this research project work includes

1. Global positioning system (GPS) for taking coordinate and mapping.
2. Note book and pen.
3. Engineering safety wears.
4. Sample bag X-Ray fluorescence (EDXRF)
5. Pulverizing machine
6. Crucibles
7. Electric current 15kv

Reagent used for the chemical analysis includes:

1. Starch soluble
2. Six (6k) each of three Cassiterite samples

DOI: 10.31695/IJASRE.2022.8.3.3

3.2. RESEARCH METHODOLOGY

Methodology is defined as the process by which different task, work or duties are appropriately implemented. This is also the process by which techniques are applied in the transforming of mineral tailings from their storage into valuable and profitable products.

The area of study was mapped with global positioning system through the collection of coordinates. After that, the mine tailings were source out by quartering sampling in order to obtain a perfect representative of the tailings for laboratory chemical analysis. The tailings were taken to Industrial Defense Corporation (IDC) Kaduna state for analysis. Three Sample were source and label A, B and C respectively. X-ray fluorescence spectrometry is a method of quantitative analysis that uses x-ray energy. The x-ray obeys the law of electromagnetic radiation which states that a body surface can absorb incident radiation and reflect the incident radiation as a minor with spherical symmetry which can transmit incident radiation and emit the radiations.

3.3. TAILINGS SAMPLE PREPARATION

The samples were pulverized (grinded to fine powder) using arget pulverizing machine (planetary micro mill pulverisette 7). The ground samples were ensured to pass 75 micro mesh sieves. This was to ensure homogeneity of the sample being pulverized.

3.4. PALLETIZATION OF THE TAILINGS SAMPLES

Six (6g) of the pulverized samples was weighed into a beaker; 1g of binding aid (starch soluble) was added. The mixture was thoroughly mixed to ensure homogeneity, which was pressed under high pressure (6 tones") to produced pellets of the samples; label and package ready for analysis.

3.5. PROCEDURE OF THE ANALYSIS

Energy dispersive x-ray fluorescence (EDXRF) spectrometer of model "Minipal 4" was used for the pellet analysis.

The pellets were carefully placed in the respective measuring positions non a sample changer of the machine. The following condition sets were made as the machine was switched on.

1. Elemental composition determination
2. Nature of the samples to be analyzed as press powder (pellet)
3. The current used as 15kv for major oxides.
4. Selected filters were "kept on" for major oxides

   The selection of filters was guided by a given periodic table used for elemental analysis. Time of measurement for each sample was 100 seconds and the medium used was air throughout. The machine was calibrated by the machine gain control, after which the respective positions of the sample were measured by clicking the respective positions of the sample changer.

3.6: EMPIRICAL FORMULA

In chemistry, the empirical formula of a chemical compound is the simplest whole number ratio of atoms present in a compound.

Achuenu Abayomi and Joro (2021) use empirical method to calculate the empirical formula of certain minerals in cassiterite. Therefore, the same principle can be applied in this research and can be shown in table 6, 7 and 8 below.

DOI: 10.31695/IJASRE.2022.8.3.3

4. RESULTS AND DISCUSSION

INTRODUCTION

Empirically, cassiterite tailings can be analysed with respect to the chemical composition of cassiterite using XRF. Each mineral in cassiterite contribute to its chemical composition. These minerals have economic values depending on the users, because what is considered as gangue minerals in one place can be considered as valuable minerals in another place, especially in recent times, where technology has advanced. The recycling of tailings depending on the value of mineral compositions in the cassiterite, for instance, if the cassiterite tailings consists of minerals of high economic value, then it is required that such cassiterite should be recycled.

Three samples of Cassiterite tailings labeled A, B and C were sampled from Mining Community Resources Center (MCRC) located at Kashim Ibrahim road, West of Mines Jos, Plateau State Nigeria to ascertain the recycling potential and utilization using chemical analysis (X-Ray Fluoresces). The results obtained from the analysis are used for ascertaining the recycling potential and utilization of the tailings. The results of the chemical analysis (XRF) are presented in the Tables below.

4.1: PRESENTATION OF RESULTS

Table 2: Chemical Analysis of tailings Sample A

Element Number	Oxide Symbol	Stoich. %wt. Concentrate	concentration factor
14	SiO_2	45.68	0.467439
13	Al_2O_3	12.99	0.7574
26	Fe_2O_3	10.55	0.699433
22	TiO_2	8.10	0.599508
40	Zr_2O_5	4.16	-
19	K_2O	3.68	0.830147
47	Ag_2O	3.50	-
20	CaO	3.47	0.714701
48	Cd_2O_3	2.31	-
11	Na_2O	1.98	0.741857
16	SO_2	1.19	-
41	Nb_2O_5	1.19	0.857352
12	MgO	0.99	0.603036
15	P_2O_5	0.20	0.436421

Table 3: Chemical Analysis of tailings Sample B

Element Number	Oxide Symbol	Stoich. %wt Conc.	concentration factor
26	Fe_2O_3	25.54	0.699433
14	SiO_2	23.31	0.467439
22	TiO_2	14.91	0.599508
13	Al_2O_3	9.26	0.7574
40	Zr_2O_5	8.36	-
48	Cd_2O_3	3.59	-
41	Nb_2O_5	3.51	0.857352
20	CaO	2.93	0.714701
47	Ag_2O	2.41	-
50	SnO_2	2.08	0.787650
19	K_2O	1.32	0.830147
15	P_2O_5	1.11	0.436421

DOI: 10.31695/IJASRE.2022.8.3.3

12	MgO	0.77	0.603036
11	Na_2O	0.47	0.741857
16	SO_2	0.43	-

Table 4: Chemical Analysis of tailings (Sample C)

¶

Element Number	Oxide Symbol	Stoich. %wt Concentration	Concentration factor
26	Fe_2O_3	28.78	0.699433
22	TiO_2	21.00	0.599508
14	SiO_2	19.74	0.467439
13	Al_2O_3	10.64	0.7574
41	Nb_2O_5	5.60	0.857352
20	CaO	4.48	0.714701
47	Ag_2O	2.22	-
19	K_2O	1.99	0.830147
40	Zr_2O_5	1.92	-
48	Cd_2O_3	1.36	-
15	P_2O_5	0.78	0.436421
12	MgO	0.77	0.603036
11	Na_2O	0.54	0.741857
16	SO_2	0.20	-

4.2. DISCUSSION OF RESULTS

The results of the analyses presented in Table 2, 3, and 4 were analysed below using table 5, 6, 7, 8; figure 5. The elemental compositions of cassiterite tailings as shown in Figure 5 show that iron and titanium oxides have higher percentage concentration in the tailings than other metallic oxides and since iron and titanium have high economic values in the extractive industry, recycling of the cassiterite tailings in the "***Jos Tin Mining Community Resource*** **Centre"** should be ascertained and recommended using empirical formula as shown in Table 6, 7 and 8 respectively.

Empirical evidence of cassiterite tailings as shown in table 6, 7, and 8 indicates that there is a high percentage of iron ore than other associated minerals. Economically, iron ore is the chief source of iron and titanium in their purest form. Therefore, this iron ore as shown Table 4, Figure 5 should be upgraded by removing other associated minerals. The grade of iron ore obtained is relatively high and can be subjected to extraction of titanium from the iron ore in order to increase the value of iron ore, so that pure iron and titanium can be successfully recovered.

Table 5: Elemental composition of MCRC tailings

SAMPLES	Al_2O_3 wt%	Fe_2O_3 wt%	TiO_2 wt%	Nb_2O_5 wt%	SnO_2 wt%	SiO_2 wt%	Zr_2O_5 wt%
Sample A	12.99 wt%	10.55 wt%	8.10 wt%	1.19 wt%	0.00 wt%	45.68 wt%	4.16 wt%
Sample B	9.26 wt%	25.54 wt%	14.91 wt%	3.51 wt%	2.08 wt%	23.31 wt%	1.92 wt%
Sample C	10.64 wt%	28.78 wt%	21.00 wt%	5.60 wt%	0.00 wt%	19.75 wt%	1.92 wt%
Total (wt %)	32.89 wt%	64.87 wt%	44.01 wt%	10.30 wt%	2.08 wt%	88.74 wt%	8 wt%
Mean Average	10.96 wt%	21.62 wt%	14.67 wt%	3.34 wt%	0.69 wt%	29.58 wt%	2.67 wt%

DOI: 10.31695/IJASRE.2022.8.3.3

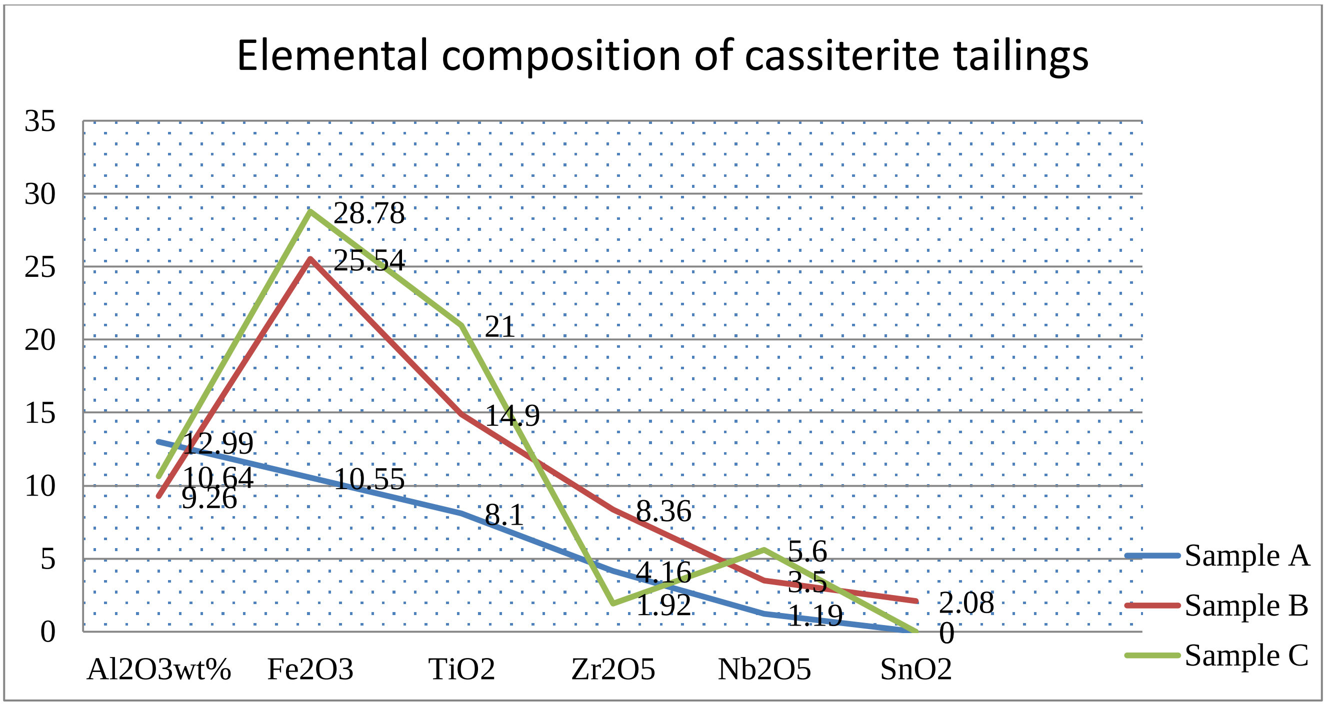


Figure 2: Graph of elemental composition of Cassiterite tailings

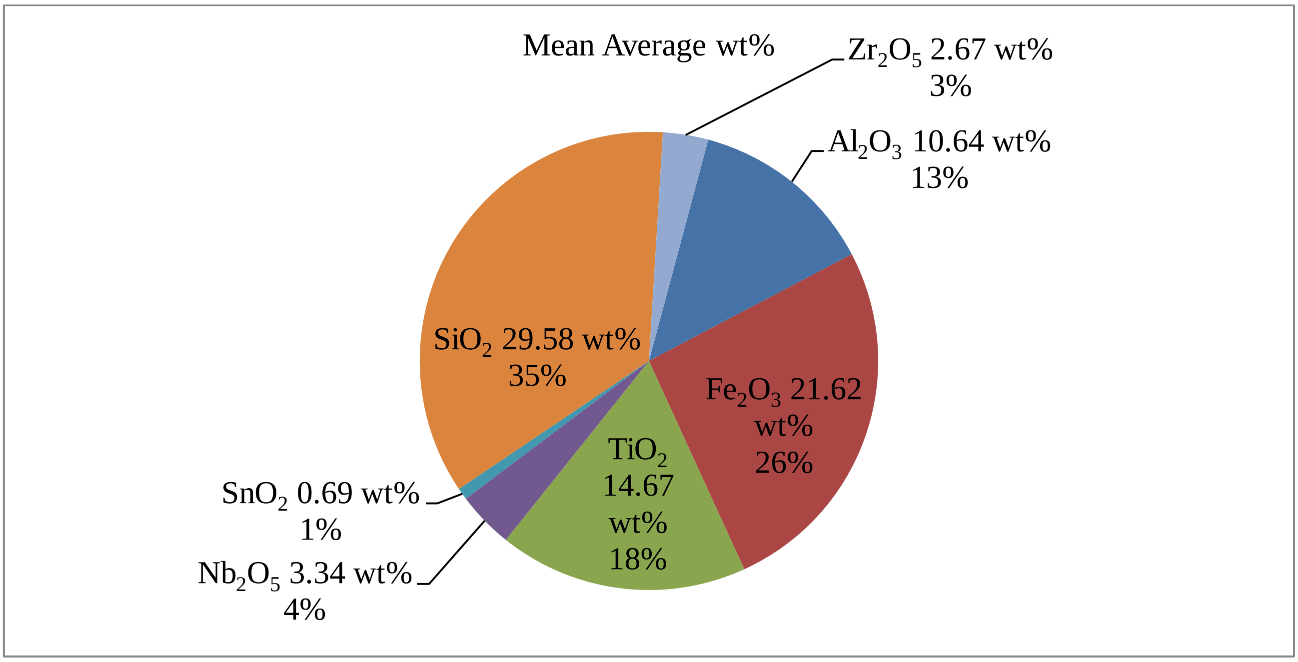


Figure 3: Distribution of mean average percentage of Cassiterite tailings

Base on the chemical analyses presented above, the percentage of valuable metals and minerals observed are substantial for recycling from the mine tailings considering the total volume in percentage of the tailings. Most of these elemental compositions have conventional/ specific quantity that are required in their respective application and if this condition is not meet, then the tailings composition is not justify to be recycled for any purposes.

DOI: 10.31695/IJASRE.2022.8.3.3

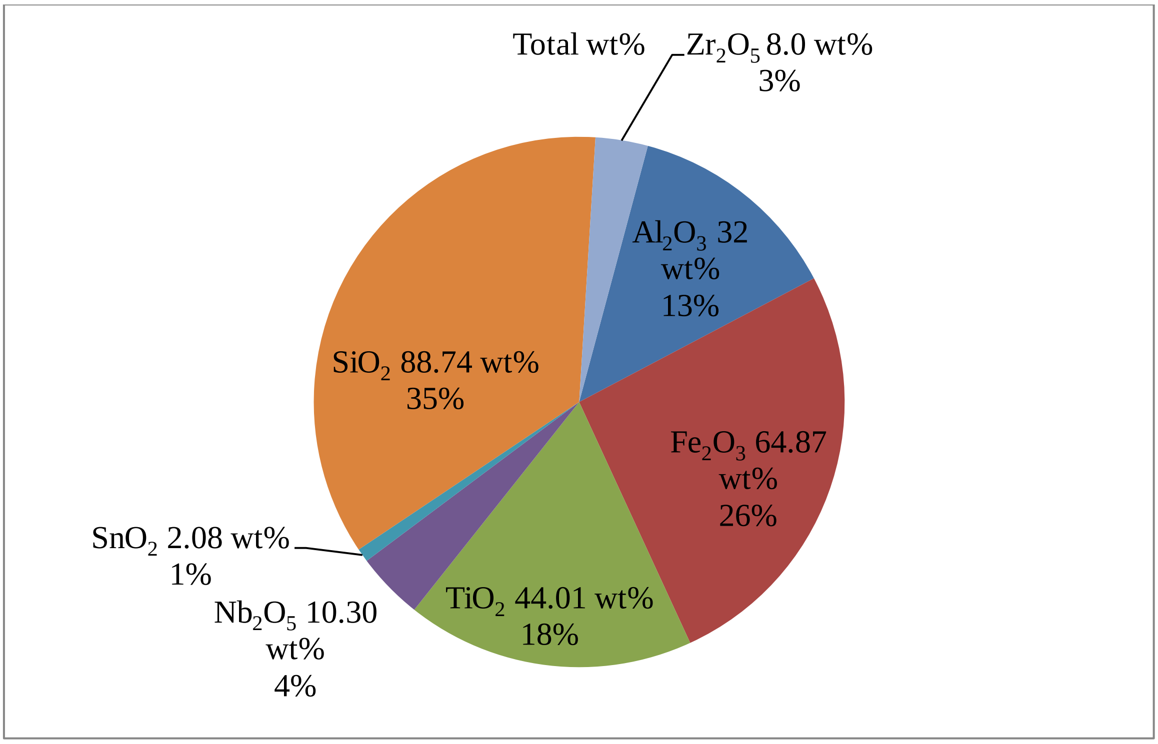


Figure 4: Distribution of percentage total weights of Cassiterite tailings

4.2.1. RECYCLING POTENTIAL OF ELEMENTAL COMPOSITION OF CASSITERITE TAILINGS.

The chemical compositions of cassiterite tailings as analysed using XRF, reflects the types of minerals to be recycled and its economic mineral potential would be ascertained, if the cassiterite tailings should be recycled or not. If the minerals to be recycled are of economic use, and meet the standard requirement according internationally accepted standard in terms of concentration of minerals in the tailings, then the tailings should be recommended for recycling.

In order to convert the compositions of the minerals in the tailings to its genetic mineral forms, empirical formula is used to convert it to its simplest form, so that the exact minerals should be ascertained. From the chemical analyses in sample A, B and C, using XRF, it indicates that iron and titanium have a higher concentration and worthy of recycling from the tailings with to its percentage compositions. The expression of its simplest formula would ascertain the genetic mineral and the economic value of the minerals would further prove its recycling potential. If the minerals to be recycled meet the standard requirement, then its recycling potential is certain

The chemical compositions of analysed cassiterite tailings include, Fe_2O_3. TiO_2, SnO_2, ZrO_2, Nb_2O_5, and their percentages are represented in table1, 2 and 3. The percentage compositions of the minerals are expressed using empirical formula in table 4, 5, and 5. The resultant minerals are used to ascertain their recycling potentia

4.2.2: EMPIRICAL CALCULATION OF CASSITERITE TAILINGS COMPOSITION IN MCRC JOS.

In chemistry, the empirical formula of a chemical compound is the simplest whole number ratio of atoms present in a compound.

Achuenu and Komolafe (2021) use empirical method to calculate the empirical formula of certain minerals in cassiterite. Therefore, the same principle can be applied in this research and can be shown in table 6, 7 and 8 below.

The elemental compositions of cassiterite tailings in Jos Tin Mining Resource Centre can be expressed as;

- Fe:Ti
- Zr:Hf
- Nb: Ta
- Al:Si

DOI: 10.31695/IJASRE.2022.8.3.3

These follow the Goldschmidt rule, which states that, ions or atoms of the same size and charge substitute themselves either across the period or down the group in the periodic table of elements during crystallization of magma.

The empirical calculation of cassiterite tailings of MCRC as shown in table 6, 7 and 8, affirmed the presence of Ilmenite in the ore as the "***Main Iron Ore***" in the cassiterite tailings.

4.2.2: MINERALS OF CASSITERITE TAILINGS USING EMPIRICAL FORMULA

Using empirical calculation, Table 6, 7 and 8, indicate that Ilmenite, Zircon, Columbite, dominate the cassiterite tailings, but some of the minerals did not meet the minimum concentration requirement for them to be recycled, therefore such minerals should be discarded during recycling.

Ilmenite meets the standard minimum concentration and therefore should be recycled. The recycling of cassiterite tailings from the study area, now depends on the ilmenite. Therefore, the mineral potential of cassiterite tailings from the study area is ilmenite.

Table 6: Empirical Representation of Cassiterite tailing composition obtained from Table 2.

Element	Iron ore		Coltan		Zircon		Tin Oxide	Others
	Fe	Ti	Nb	Ta	Zr	Hf		
Percentage composition (%)	10.55	8.10	1.19	0.00	4.16	0.00	0.00	0.00
Atomic number	56	47	82	146	80	144	50	
Mole ratio	0.19	0.17	0.134	0.00	0.05	0.00		
Mole ratio/smallest	1	1	1	0	1	0		
Empirical formula	Fe	Ti	Nb	0	Zr	0		
Oxidation number	+3	+4	+5	0	+4	0	o	
Number of oxygen atom	3	4	5	0	4	0	0	
Molecular oxygen formula	O_3	O_4	O_5	0	O_4	0	0	
Chemical formula	$FeTiO_3$		Nb_2O_5		ZrO_2		No SnO_2	0.00
	$FeTiO_3$		$FeNb_2O_6$		ZrO_2			
Genetic name	Ilmenite		Columbite		Zircon		No Tin	

Table 7: Empirical Representation of Cassiterite tailing composition obtained from Table 3.

DOI: 10.31695/IJASRE.2022.8.3.3

Element	Iron ore		Coltan		Zircon		Tin Oxide	others
	Fe	Ti	Nb	Ta	Zr	Hf		
Percentage composition (%)	25.54	14.91	3.51	0.00	1.92	0.00	2.08	0.00
Atomic number	56	47	82	146	80	144	50	
Mole ratio	0.46	0.32	0.04	0.00	0.02	0.00		
Mole ratio/smallest	1	1	1	0	1	0		
Empirical formula	Fe	Ti	Nb	0	Zr	0		
Oxidation number	+3	+4	+5	0	+4	0	+4	
Number of oxygen atom	3	4	5	0	4	0	4	
Molecular oxygen formula	O_3	O_4	O_5	0	O_4	0	O_4	
Chemical formula	$FeTiO_3$		Nb_2O_5		ZrO_2		SnO_2	
	$FeTiO_3$		$FeNb_2O_6$		ZrO_2			
Genetic name	Ilmenite		Columbite		Zircon		Tin	

Table 8: Empirical Representation of Cassiterite tailing composition obtained from Table 4.

Element	Iron ore		Coltan		Zircon		Tin Oxide	Others Aluminum and sand
	Fe	Ti	Nb	Ta	Zr	Hf		
Percentage composition (%)	28.78	21.00	5.60	0.00	1.92	0.00	0.00	30.39
Atomic number	56	47	82	146	80	144	50	
Mole ratio	0.51	0.45	0.07	0.00	0.02	0.00		
Mole ratio/smallest	1	1	1	0	1	0		
Empirical formula	Fe	Ti	Nb	0	Zr	0		
Oxidation number	+3	+4	+5	0	+4	0	0	
Number of oxygen atom	3	4	5	5	4	4	0	
Molecular oxygen formula	O_3	O_4	O_5	O_5	O_4	O_4	0	
Chemical formula	$FeTiO_3$		Nb_2O_5		ZrO_2		No SnO_2	
					ZrO_2			

DOI: 10.31695/IJASRE.2022.8.3.3

	$FeTiO_3$	$FeNb_2O_6$			
Genetic name	Ilmenite	Columbite	Zircon	No Tin	

From the empirical expression in Table 6, 7 and 8, the minerals obtained from cassiterite tailings in Table 2, 3 and 4 using empirical method includes;

i. Tin
ii. Columbite
iii. Zircon
iv. Ilmenits

Iron ore in cassiterite tailings occurs as Haernatite (Fe_2O_3) to rutile ratio in composition, that is Fe_2O_3: TiO_2. XRF analyses revealed the occurrence of Fe_2O_3: TiO_2 in approximate proportion and then can be reduced to the simplest form using empirical formula.

Igneous rock is the source of cassiterite rich in minerals such as ilmenite, ulvospinel, tin, zircon & sand. Achuenu & Komalefe, (2021), stipulated that, there must be a solid solution among the iron and titanium provided that there is drop in temperature at an igneous temperature during formation of cassiterite. This means that magnetite & Haematite rarely occur at an igneous temperature, except if the temperature cools rapidly to precipitate magnetite and haematite as in Basaltic rock.

The empirical calculations of the percentage compositions of cassiterite tailings in Jos Tin Mining Community Resource Centre revealed by XRF analyses were shown in table 6, 7 and 8 above. The empirical calculations indicate that ilmenite is the main genetic minerals of iron ore in the cassiterite tailings. Therefore, the cassiterite tailings would be recycled as ilmenite.

Titanium and iron can be extracted from the ilmenite using some acid reagents. The fluoride compounds include

1. Hydrofluoric acid (HF)
2. Fluosilicac acid (H_2SiF_6)
3. Alkali fluosilicate
4. Ammonium bifluoride (NH_4Hf_2)

$H_2SiF_6 + FeTiO_3 \rightarrow SiO_2 + FeF_2 + Ti^{+4} + 6HF + H_2O$

Titanium is extracted from its ore rutile TiO_2. it is first converted into titanium (iv) chloride which is then reduced the titanium using either Mg or Na.

The ore rutile, is heated with chlorine and coke at a temperature of about 1000^0C

$$Ti^02+2cl2+c \rightarrow Ticl_4 + 2CO$$

$$Ticl_4 + 2Mg \rightarrow 2Mgcl_2 + Ti$$

Experiments have shown that, Fe and Ti can be cheaply extracted using H_2SiF_6, Fluorosilic acid. This testifies that cassiterite tailings of MCRC can be ascertained for recycling using empirical evidence.

4.2.3: ECONOMIC VALUES OF ILMENITE.

The chief source of Iron and Titanium are the iron ores such haemitite, magnetite, ulvospinel and ilmenite. Of these minerals, ilmenite dominates the cassiterite tailings in MCRC, therefore ilmenite would be the chief source iron and titanium from the study area and are described below;

1. **IRON (III) OXIDE (Fe_2O_3): (Total = 64.87 wt%, Avg. Mean = 21.62 wt %)**

Iron (iii) oxide or ferric oxide is the inorganic compound with the formula Fe_2O_3. It is one of the three main oxides of iron, the other two being iron(I) oxide (FeO_3), which is rare; and iron (II,III) oxide (Fe_2O_3), which also occurs naturally as the mineral magnetite. As the mineral known as hematite, (Fe_2O_3) is the main source of iron for the steel industry. Fe_2O_3 here is a byproduct of Cassiterite as of the time of processing refers to as tailings in the process. Iron (III) oxide has wide application such as in additives

DOI: 10.31695/IJASRE.2022.8.3.3

for cement making, along with CaO and other inorganic oxides. According to (Veroustraete, 2015), the percentage of Fe_2O_3 required for making Portland cement is shown below.

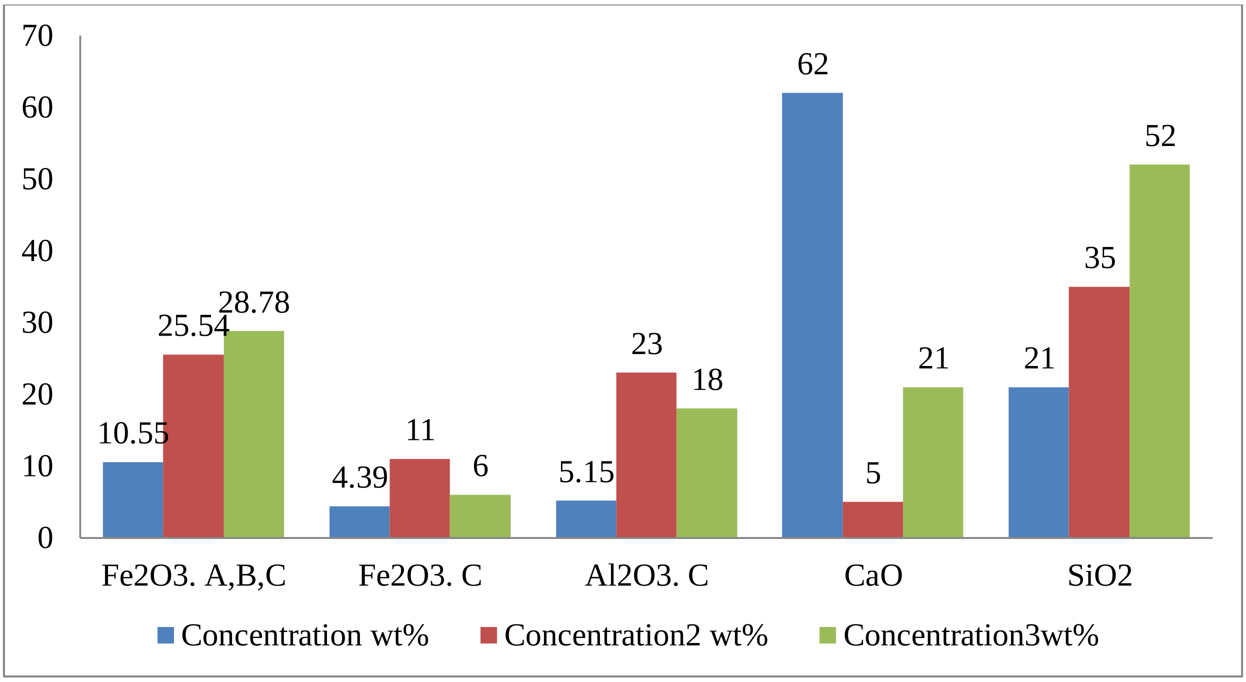


Figure 5: Percentage of Fe_2O_3 required for cement making

Cement is a binder that sets and hardens and can bind other material together. It is carried out by heating limestone's such as clay to 1450^0C in a kiln in a process known as calcinations to form CaO from $CaCO_3$ and is then blended with the above additives that are included in the mix. The resulting hard substance called "clinker" is then ground with a small amount of gypsum into powder to make Portland cement.

Fe_2O_3 is used in concrete aggregate test in order to evaluate the quality of cast iron concrete which include compressive strength (f_{cu}), flexural strength (f_r), indirect tensile strength (f_t) and modulus of elasticity (Ec) for four sustainable concretes. The percentages of iron in wt% are 0.5%, 0.75%, and 1%. The result shows that the iron fillings amount is increased to 1.0% which resulted in increasing percentage of compressive strength (f_{cu}), flexural strength (f_r), indirect tensile strength (f_t) and modulus of elasticity (Ec) with 10%, 32%, 42%, and 11% for geopolymer concrete with recycled aggregate of irons respectively. But when this same iron is used in the making of steel, it can easily be rusted when exposed to some environmental conditions, thus reducing its strength, when used as a beam; it reduces the allowable span of the member (Milani, 2018).`

Table 9: Summary of chemical data for a selection of Portland cement in Ghana (Taylor, 1997), (Mindess and Gray, 1998)

COMPONENT	MINIMUM wt%	AVERAGE wt%	MAXIMUM wt%
SiO_2	18.40	21.02	24.50
Fe_2O_3	0.16	2.85	5.78
Al_2O_3	3.10	5.04	7.56
CaO	58.10	64.18	68.00
MgO	0.02	1.67	7.10
SO_2	0.00	2.58	5.35
Na_2O_3	0.00	0.24	0.78
K_2O	0.04	0.70	1.66
Equivalent Alkalis	0.03	0.68	1.24
Free lime	0.03	1.24	3.68

They analyses that during cement hydration, CaO in conjunction with SiO2, Al_2O_3, and Fe_2O_3 leads to hardening of Portland cement due to the formation of calcium aluminosilicates and aluminoferrite.

With the acceptable level of Fe_2O_3 and other elemental composition in the tailings and considering the required percentage needed for industrial purposes (cement as a construction material) and its suitability to be used, this shows that the

DOI: 10.31695/IJASRE.2022.8.3.3

percentage composition of Fe_2O_3 and other composite elements are economical and justify to be recycle and be used for the above products as 25wt% is gives the standard acceptable value in tailings sufficient for recycling.

2. ALUMINIUM OXIDE (Al_2O_3): (Total = 32.89 wt%, Avg. Mean = 10.96 wt %)

Aluminium oxide (Al_2O_3) is a chemical compound of aluminium and oxygen. It is the most occurring of several aluminium oxides and specifically identified as aluminium (III) oxide. Al_2O_3 an electrical insulator but has a relatively high thermal conductivity for aceramic materials. Its hardness makes it suitable for use as an abrasive and as a component in cutting tool. Aluminum oxide is responsible for the resistance of metallic aluminium to weathering. Other major uses of Al_2O_3 are as refractories, polishing, water purification to remove water from gas stream, as a catalyst in industry. In making sheet glass, it is customary to use 6% of CaO and 4% of MgO and in bottle glass about 2% Al_2O_3 is present with other materials (Britannica, 2019). Such quantity of Al_2O_3 in the samples cannot be used in the making of abrasive materials because aluminium oxide and silicon carbide in abrasive materials account for as much as 80 to 90% of the total quantity of abrasive grain produced domestically (Hight, 1983). Porcelain insulator contains about 30% of Al_2O_3 together with fluxes, barium carbonate, talc, and manganese dioxide.

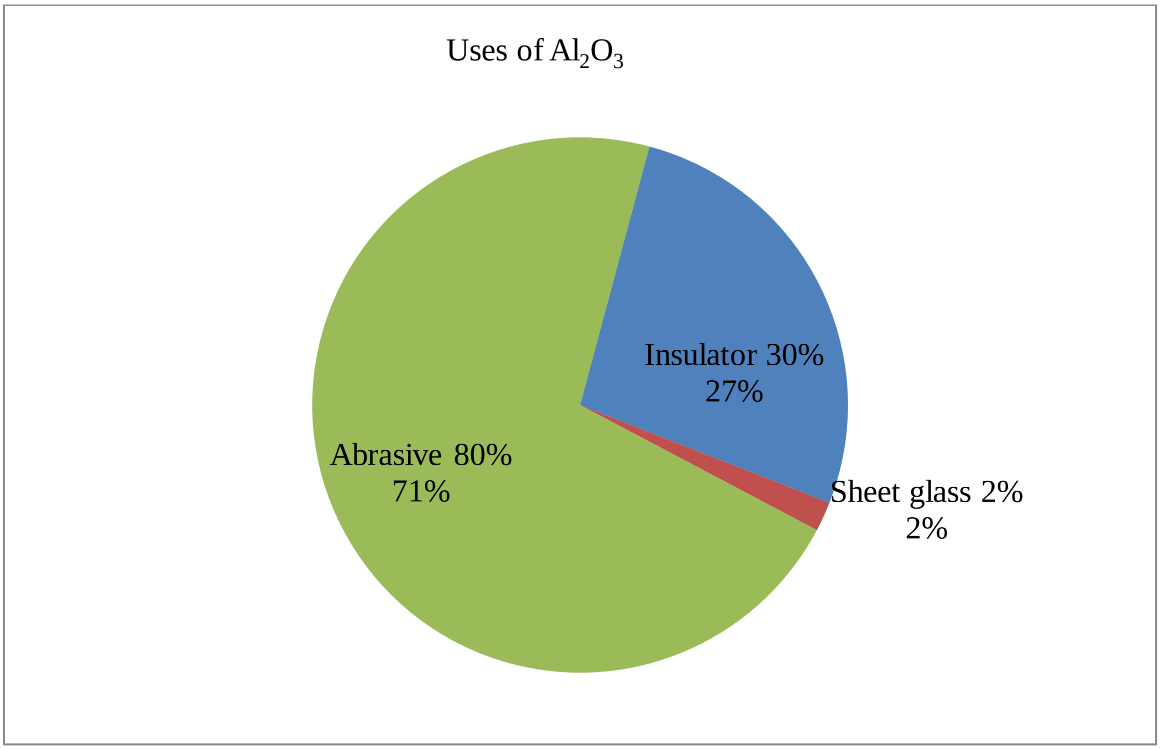


Figure 6: Distribution of percentage use of Aluminium Oxide

With the acceptable level of Al_2O_3 and other elemental composition in the tailings such as MgO, and considering the required percentage needed for industrial purposes (sheet glass making, insulator with exception of abrasion) and its suitability to be used, this shows that the percentage composition of Al_2O_3 and MgO composite elements are economical and justify to be recycle and be used for the above products and others.

3. TITANIUM (TiO_2): (Total = 44.01 wt%, Avg. Mean = 14.67 wt %)

Titanium oxide is a naturally occurring oxide of titanium. When used as pigment, it is called titanium white etc. generally, it is sourced from ilmenite, rutile, and anatase. It has a wide range of applications, including paint, sunscreen, food colouring. It has been estimated that titanium dioxide is used in two-thirds of all pigments, and pigments based on the oxide have value at $13.2 billion (Schonbrun, Zack, 2018). According to a survey in china, titanium oxide is primarily used in chemical application such as heat exchanger (57% TiO_2), titanium anode (20% TiO_2), titanium container (16% TiO_2), quality white latex paint usually contain 20-20% of TiO_2, sunscreen used in body creams contains 15-20% zinc oxide + at 7.5% TiO_2 because it has the ability to absorb UV light or radiation from the sun (Megha, 2016).

DOI: 10.31695/IJASRE.2022.8.3.3

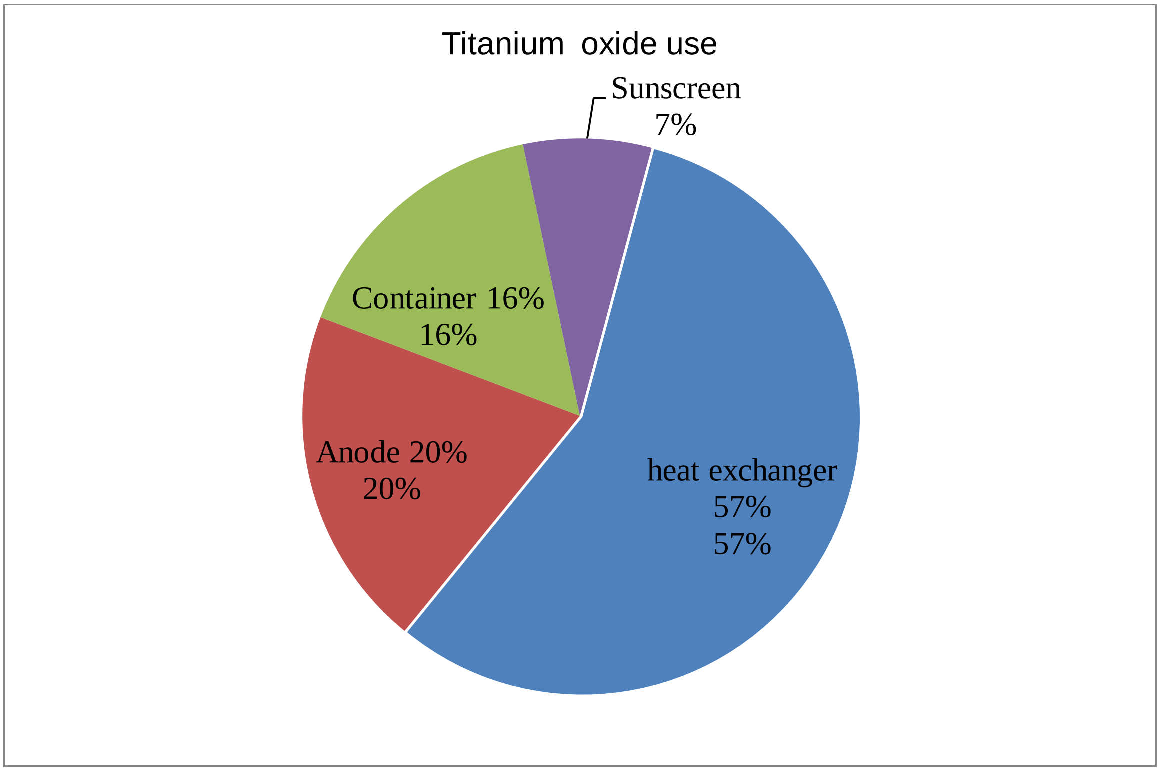
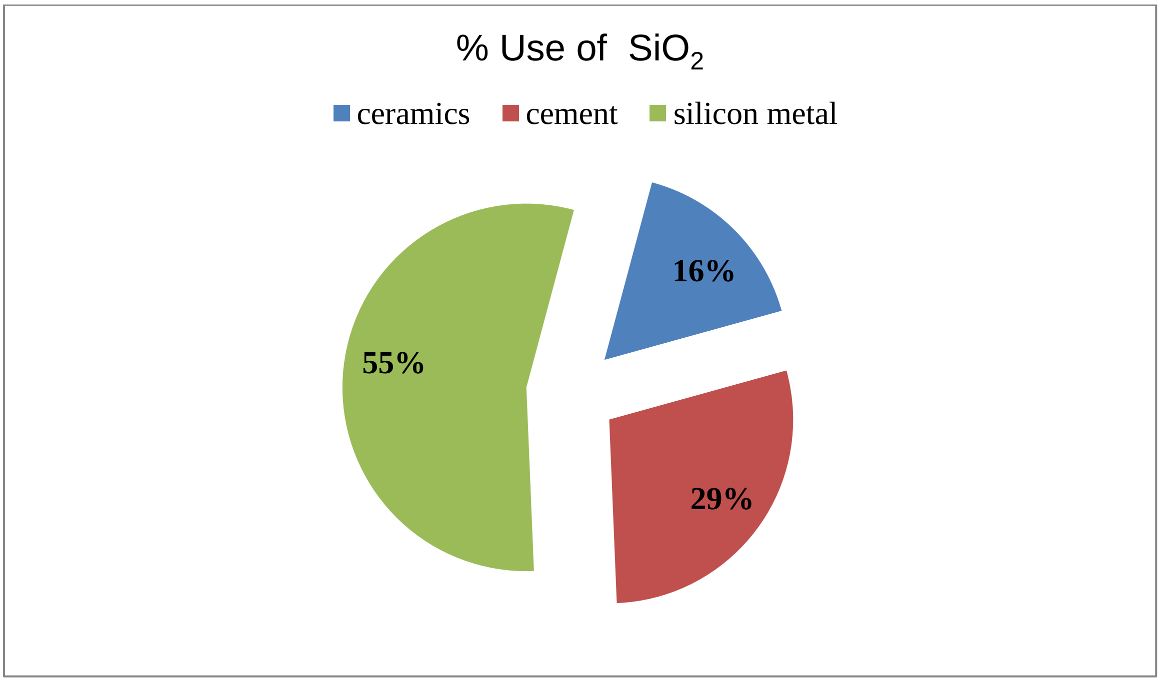


Figure 7: Distribution of percentage use of Titanium oxide

With the acceptable level of TiO_2 in the tailings and considering the required percentage needed for industrial purposes (heat exchanger, container making and anode) and its suitability to be used, this shows that the percentage composition of TiO_2 is economical and justify to be recycle and be used for the above products and others with the exception of heat exchanger that requires high percentage of TiO_2.

4. SILICA (SiO_2): (Total = 88.74 wt%, Avg. Mean = 29.58 wt %)

Silica is a white or colourless crystalline compound mainly a quarts, sand, flint and many other materials. Use for making glasses, concrete, cements, ceramics, pottery etc. as an additive for making cement, silicon is require of about 52%, 99.5% for making silicon metal in form of metallurgical grade gravel with combine materials such as coke, coal etc (Mazur, 2019). High temperature traditional ceramics bodies tend to have up to 30% silica whereas low fire ones have much less or none (because of refractory nature) (Sohngen and Hassen, 2003). This ceramics demonstrate increased performance with greater brightness, reflectance, color, consistency, and absorption of oil etc.



DOI: 10.31695/IJASRE.2022.8.3.3

Figure 8: Distribution of percentage use of silica

With the acceptable level of SiO_2 in the tailings and considering the required percentage needed for industrial purposes (ceramics, cement, silicon metal) and its suitability to be used, this shows that the percentage composition of SiO_2 is economical and justify to be recycle and be used for the above products and others with the exception of heat exchanger that requires high percentage of SiO_2.

5. **Niobium oxide (Nb_2O_5): (Total = 10.30 wt%, Avg. Mean = 3.34 wt %)**

This is also known as columbium and has applications in jewelry as hyper allergenic and used mostly in alloys. The largest part in special steel such as that used in gas pipelines contains a maximum of 0.1% of Nb_2O_5. This small percent of Nb_2O_5 enhances the strength of the steel. The temperature stability of Niobium-containing super alloys is important for its use in jets and rockets engines. Nb_2O_5 is use in various super conductor materials containing titanium and tin. This includes super conducting magnet in magnetic resonance imaging (MRI) scan (Knapp, Brian, 2002).

6. **Tin (SnO_2): (Total = 2.08 wt%, Avg. Mean = 0.69 wt %)**

Tin oxide has been used primarily as an opacifier and as white colorant in ceramics glazes in amount of 3-15% in all type of glazers for many years. Tin oxide SnO_2, is used to produce pink colour using chrome and tin in the ration of 0.5% to 7.5%. Tin used in tin-lead soft solders typically requires 30-70% or more of SnO_2 in it (Britannic, 2019). Tin bronzes are alloys of tin, with copper, copper-lead, and copper-lead-zinc. Cast bronzes contains up to 12%tin, for special application such as bells and musical instruments, tin percentage required is up to 20% (Britannic, 2019). However, in application where bearings are highly loaded, the strength of tin-rich alloys may be insufficient, so that an alloy of 80% aluminum and 20% tin is constantly used. This alloy, bonded to a steel or bronze shell, is widely used in diesel engines and in the high-performance engine of most engines.

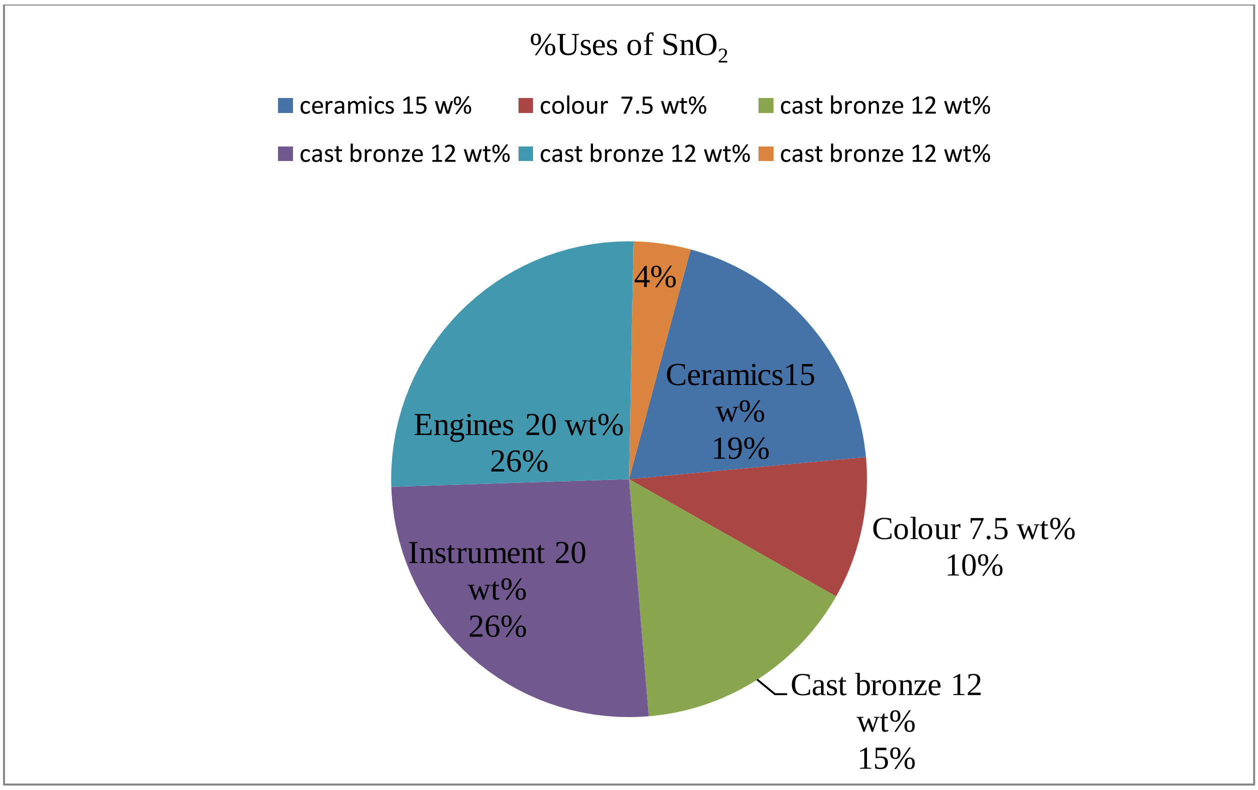


Figure 10: Distribution of percentage use of tin oxide

The percentage of tin in this analysis is not encouraging at all considering the high demand of it in the industry. With this, I assumed that the efficiency of the mill processing machines was so high that little or no tin is left in the tailings for recovery and does not justify economic recovery for utilizations its stand.

7. **Zircon (Zr_2O_5): (Total = 8.0 wt%, Avg. Mean = 2.67 wt %)**

Zircon is a silver-gray transition metal, a type of elements that is malleable and ductile stable compound. Is highly resistant to corrosion and can form an alloy. Use in steel alloy with tin, as heat exchanger, in pipes making, fittings bulbs, lamps, deodorants. Other uses for zirconium include furnace bricks, lab crucibles, television glass, opacification

DOI: 10.31695/IJASRE.2022.8.3.3

and removing residual gas from vacuum tubes and as a hardening agent in alloys such as steel, according to (Lenntech, 2019). According to information furnished by the principal zircon dealers, the distribution, by used, for 1951 was as follows: porcelain enamel 7%, pottery 7% (to reduce the amount of SiO2 or increase flux (to melt the glaze better), electrical and chemical porcelain 3%, refractory 45%, gas 1%, metals and alloys 7%.

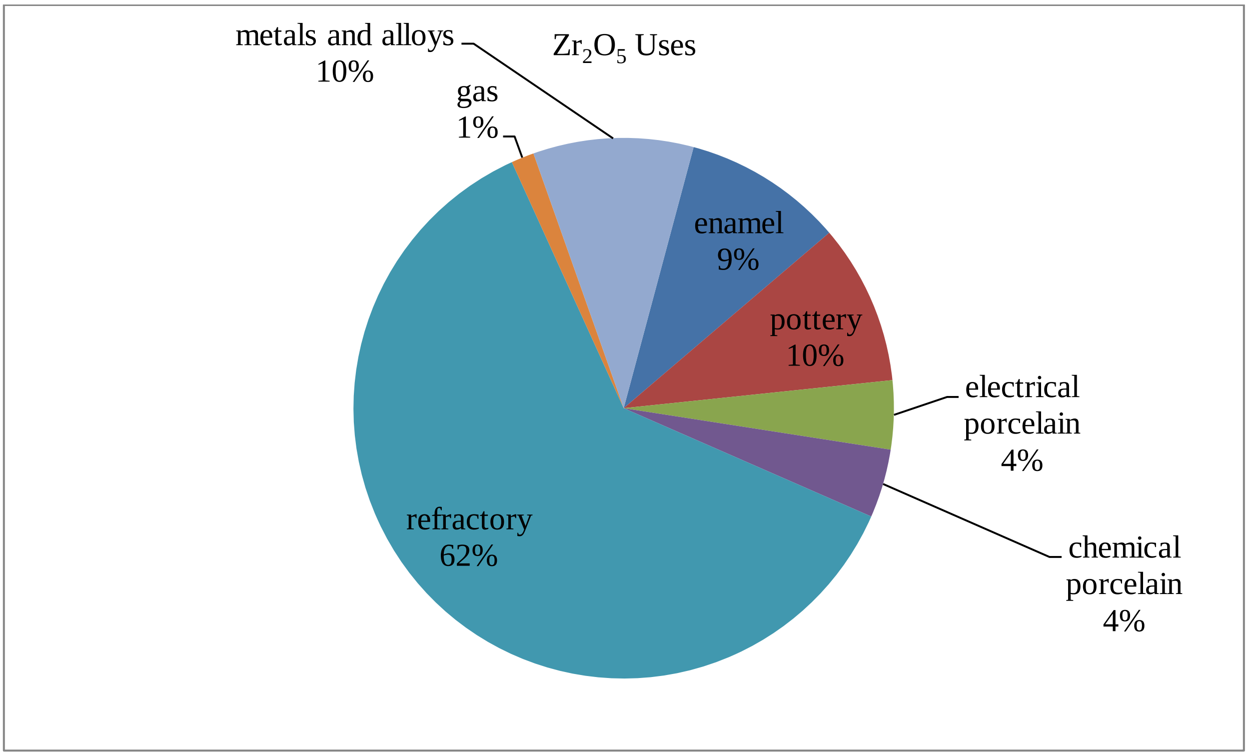


Figure 11: Distribution percentage use of zirconium oxide

With the acceptable level of zircon in the tailings and considering the required percentage, the zircon can be utilized in many industrial field listed above except for refractory where high percentage is required.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. SUMMARY

Mine tailing recycling is the process of converting the materials that are regarded as waste or gangue into something economical and beneficial. Utilization involves the use of these mine recycled products in a way that it's generating income.

Cassiterite tailings were sourced from Mining Community Resource Centre (MCRC) for ascertaining the recycling potential and utilization through the use of X-ray fluoresces to determine the elemental composition of the mine tailings for potential recycling. The result of the analysis shows that the elements are composed of inorganic oxides as shown in chapter four. Three samples in all were sourced and analyses for the basic elements of interest in this research work.

The total percentage of iron oxide in the combine sample was calculated and found to be 64.87 wt%, aluminium oxide 32.89 wt%, titanium oxide 44.01 wt%, niobium oxide 10.30 wt%, tin oxide 2.08wt%, silica oxide 88.74wt%, zircononium oxide 8.0wt% respectively while the mean average of the composition was aluminium oxide 10.96wt%, iron oxide 21.62 wt%, titanium oxide 14.67 wt%, niobium oxide 3.34 wt%, tin oxide 0.69 wt%, silica oxide 29.58 wt% and zirconium 2.67 wt% respectively with applications in different industrial field and at required specific quantity.

The compositions of these oxides as revealed by analyses were converted to their genetic minerals using empirical calculation as shown in table 6, 7 and 8 above. These genetic minerals include Tin, Ilmente, Zircon, and Columbite. As well sand. In this case the minerals with the highest recycling potential would be recycled according its economic values e.g., Ilmenite. Ilmenite is the main iron ore in the ***"Cassiterite Tailings***" of MCRC, Jos.

5.2. CONCLUSION

From the results of analyses carried out on MCRC mine tailings, the result shows that the tailings are made up of low grade metallic and non-metallic oxides which can be economically recovered and recycled into different industrial products such

DOI: 10.31695/IJASRE.2022.8.3.3

as cement making, glass, ceramics, bricks etc. in relation to their required percentage in such products. Fe_2O_3, SiO_2, TiO_2, Al_2O_3 are the chemical compositions of cassiterite tailings and its genetic mineral Ilmenite, and sand show high concentration and recovery rate with wide application.

The absence of tin (SiO_2) which is the major mineral of Cassiterite ores in sample A and C possibly shows that the efficiency of the beneficiation and separation in initial stage was so high that little or no tin was left in the tailings and therefore have low recovery and recycling potential.

Finally, the type of iron ore in the tailings as revealed by empirical evidence is Ilmenite. Based on these analyses, the cassiterite tailings of Jos Tin MCRC has a high recycling potential.

5.3. RECOMMENDATION

Considering the percentage of the elemental composition of these tailings, wealth, and materials can be generated from these unwanted minerals that are consider as tailings even after the main mineral of interest is beneficiated out, Hence, the following recommendation.

1. The Company/Government should look into the negative impact these tailings can have in the community and profound a solution to conserved them in a confine manner to avoid its hazardous effect. I.e. provision of proper management facility.
2. The Company/Government if resources are available should look into the potential of recycling these tailings which have economic values by providing the necessary processing and recycling facilities capable of harnessing these valuable minerals from the tailings.
3. Further research should be carried out on these tailings for potential harmful compounds before recycling.
4. The company/government look into this project research to see the recycling potential of the tailings such as the high in concentration of Fe_2O_3, TiO_2, Al_2O_3, SiO_2, etc. which justify recycling potential in cement industry, pottery, etc. for creation of wealth.

REFERENCE

1. Abadjiev, C.B. (1976) Seepage through Mill Tailings Dams, Trans, of the 12th ICOLD, Mexico City, 1, 381–93.
2. Abadjiev, C.B. (1985) Estimate of the physical characteristics of deposited tailings in the tailings dam of nonferrous metallurgy, Proc., 11th Int. Conf. on Soil Mechanics and Foundation Eng. , San Francisco, 3, 1231–4.
3. B. K. Parekh and W. M. Goldberger, "An assessment of technology for the possible utilization of Bayer process muds", published by the U. S. Environmental Protection Agency, EPA 600/2-76-301.
4. Balkau, F. (1998). Environmental issues in tailings management - Case studies on tailings management, International Council on Metals and the Environment (ICME), United Nations Environment Programme (UNEP).pp. 11-12
5. Bascetin, A., Tuylu, S., Adiguzel, D., Akkaya, U., and Binen, I. S. 2013. “Investigation of Suitability of Pb-Zn Mine Tailings for Surface Paste Disposal.” 23rd World
6. Benckert, A. and J. Eurenius (2001). Tailings dam constructions - Seminar on safe tailings dam constructions. Gallivare, Swedish Mining Association, NaturVardsVerket, European Commission pp. 30-36
7. Blight, G. E. (1998).Insights into Tailings Dam Failure - Technical and Management Factors. International Workshop on Managing the Risks of Tailings Disposal, May 22-23, 1997, Stockholm, Sweden, International Council on Metals and the Environment (ICME), United Nations Environment Programme (UNEP): pp. 17-28.
8. Brehaut, H. (1998). A Management Perspective - Case studies on tailings management, International Council on Metals and the Environment (ICME), United Nations Environment Programme (UNEP).pp. 3-4
9. Cai, J.W., Zhang, S.B., Hou, G.X. and Wang, C.M. (2009), “Effects of ferrous mill tailings as aggregates on workability and strength of concrete”, J. Wuhan Univ. Technol., 31(7), 104-107. Cao, W. (2007), “Study on properties of recycled tire rubber modified asphalt mixtures using dry process”, J. Constr. Build. Mater., 21, 1011-1015.
10. Caldwell, J.A., Ferguson, K., Schiffman, R.L. and Van Zyl, D. (1984) Application of Finite Strain Consolidation Theory for Engineering Design and Environmental Planning of Mine Tailings Impoundments,
11. Calvert, J.B., 2000, Tin 4, available at www.du.edu/~jcalvert/phys/tin.htm
12. Carmen Falagen, Barry M. Grail, David Barrie Johnson.. October 2016-2017. New approaches for extracting and recovery metals from mine tailings. Article in mineral engineering 106
13. Coumans, C. (2002). Submarine Tailings Disposal - STD Toolkit, MiningWatch Canada, Ottawa and Project Underground, Berkeley, CA, USA:: 16.

DOI: 10.31695/IJASRE.2022.8.3.3

14. D. R. Nagaraj "Minerals Recovery and Processing" in Kirk-Othmer Encyclopedia of Chemical Technology, Wiley-VCH doi : 10.1002/0471238961.1309140514010701.a01.pub2
15. Daniel, A., & Downing, B.W. (2011). Investigating the Reprocessing of Carolin Mine Tailings. Tailings and Mine Waste 2011, Vancouver, Canada. 53-65.
16. Das, S.K., Kumar, S. and Ramachandrarao, P. (2000), “Exploitation of iron ore for the development of ceramic tiles”, J. Waste Manage., 20, 725-729.
17. Davies, M. P. (2001). "Impounded mine tailings: what are the failures telling us?." CIM Distinguished Lecture 2000-2001. The Canadian Mining and Metallurgical Bulletin 94(1052): pp. 53-59.
18. Davies, M. P. and S. Rice (2001). An alternative to conventional tailing management – “dry stack” filtered tailings, AMEC Earth & Environmental, Vancouver, Canada: 10.
19. Davies, M. P., Martin, T. E., and Lighthall, P. 2000. “Mine Tailings Dams: When Things Go Wrong.” Tailings Dams 2000, Association of State Dam Safety Officials, U.S. Committee on Large Dams, LasVegas, Nevada: 261-73.
20. Denver, Colorado, Lianyang Zhang, Ph.D., P.E. U.S. EPA Hardrock Mining Conference 2012: Advancing Solutions for a New Legacy April 3-5, 2012.
21. Diehl, P. (2006). "Chronology of major tailings dam failures." http://www.wiseuranium.org/mdaf.html. Retrieved 07th February 2006.
22. DME (1998). Guidelines on the Development of an Operating Manual Tailings Storage, Department of Minerals and Energy, Western Australia.ISBN: 0730978052.41
23. DME (2000). Water Quality Protection Guidelines No. 2: Mining and Mineral Processing - Tailings facilities, Water and Rivers Commission & Department of Minerals and Energy, Western Australia: 11.
24. DPI (2003). Management of Tailings Storage Facilities - Environmental Guidelines, Department of Primary Industries, Victoria - Minerals & Petroleum Division:.63
25. Emery, A. (1997).Tailings Disposal, Managing the Risks - The Role of Corporate Policies. International Workshop on Managing the Risks of Tailings Disposal, May 22-23, 1997, Stockholm, Sweden, International Council on Metals and the Environment (ICME), United Nations Environment Programme (UNEP): pp. 65-71.
26. Engel, (2002). What are tailings? Their nature and production, www.tailpro.com
27. Engineering Materials, Prentice-Hall, Upper Saddle River, NJ, USA, 1998.
28. EPA (1994). Technical Report - Design and Evaluation of Tailings Dams, U.S. Environmental Protection Agency, Office of Solid Waste, Washington:.63
29. Evans, K., "The History, Challenges and new developments in the management and use of Bauxite Residue", J. Sustain Metall. May 2016. doi : 10.1007/s40831-016-00060-x .
30. Evans, Ken; Nordheim, Eirik; Tsesmelis, Katy (2012)."Bauxite Residue Management".
31. Fourie, A. B. (2003). In Search of the Sustainable Tailings Dam: Do High-Density Thickened Tailings Provide the Solution, School of Civil and Environmental Engineering, University of the Witwaterstrand, South Africa:: 12.
32. Frank Veroustraete, 2nd Feb, 2015. Proportion of cement constituent in production, University of Antwerp.
33. Gabriele Milani, 2018. Effect of iron filings on the mechanical properties of different types of sustainable concrete. Department of Architecture technical university of Milan, Milan Italy.
34. Garcia, C., A. Ballester, et al. (2005). "Pyrite behaviour in a tailings pond." Hydrometallurgy 76(1-2): pp. 25-36.
35. Gelabert, E. R. and F. Tavares (2003). Position Paper on the European Commission Proposal for a Directive on the Management of Waste from the Extractive Industries, World Wildlife Fund (WWF), Brussels, Belgium:: 43.
36. Gibson, O., 2002, “Tin Smelting in Nigeria – the Challenge of our time.” Proceedings of the 19th Annual Conference/AGM of the Nigerian Metallurgical Society, pp. 47 – 60. [
37. Gipson, A. H., Jr (1998). Tailings disposal - The last 10 years and future trends. Fort Collins, Colorado, 26-29th January 1998 A. A. Balkema.ISBN: 905410922X.pp. 127-135
38. Golder (1999).Operating Manual for the Tailings Management Facility at the Lisheen Mine, Ireland. Report No. 996401mart28, Golder Associates:: 81.
39. H. F. W. Taylor, Cement Chemistry, Thomas Telford, London, UK, 2nd edition, 1997.
40. J. F. Young, S. Mindess, R. J. Gray, and A. Bentur, The Science and Technology of Civil engineering materials, prentice-hall, upper saddle river, NJ, UAS, 1998
41. Jakubick, A., G. McKenna, et al. (2003). Stabilisation of Tailings Deposits: International Experience. Mining and the Environment III, Sudbury, Ontario, Canada, 25-28 May, 2003:. pp. 1-9.
42. Janine Figueiredo, Antonio Fiuza, (2018). A sustainable tailings reprocessing project: A case of study in Portugal
43. Jim Kuipers, PE, Kuipers & Associates, (2015). Mine tailings fundamentals: mine tailings facility dersign and operation-part 1. U.S. EPA contaminated site clean-up information webinar series may 19-20, 2015.
44. Megha Trivedi and Jenny Murase, (2016). Titanium Dioxide in sunscreen, November 29th, 2016

DOI: 10.31695/IJASRE.2022.8.3.3

45. Pulford, I.D. 1991. A review of methods to control acid generation in pyritic coal mine waste, pp. 269-279 In Proc. of The International Conference on Land Reclamation: An End to Dereliction? University of Wales College of Cardiff.
46. Pullford, I.D. 1991. A review of methods to control acid generation in pyrite coal mine waste, pp. 269-279 in proc. Of the international conference on land reclamation: an end to dereliction? University of Wales college of Cardiff.
47. Ritcey, G. M. (1989). Tailings management : Problems and solutions in the mining industry. Amsterdam ; New York, Elsevier.ISBN: 0444873740 (vol. 6).xx, 970
48. Ritcey, G. M. (1989). Tailings management : Problems and solutions in the mining industry. Amsterdam ; New York, Elsevier.ISBN: 0444873740 (vol. 6).xx, 970
49. Robertson, A. MacG. and van Zyl, D.J.A. (1980) Design and construction options for surface uranium tailings impoundments, Proceedings of the First International Conference on Uranium Mine Waste Disposal, Soc. of Mining Engrs , AIME, Chapter 11, pp. 101–119.
50. Schonbrun, Zach. “The quest for the next billion-dollar color” Bloomberg.com.retreived 24 April 2018.
51. Tony Hansen, Sohngen, (2003, 2008, 2015). The material Silica, digitalifeinsight live.com
52. Vick, S. G. (1990). Planning, design, and analysis of tailings dams. Vancouver, BiTech.ISBN: 0921095120.2nd Edition.xi, 369
53. Vick, S.G.1 (1983) Planning, Design, and Analysis of Tailings Dams , John Wiley and Sons.
54. Vogt, C. 2012. “International Assessment of Marine and Riverine Disposal of Mine Tailings.” A Report Prepared for LC/LP, IMO and UNEP GPA: 1-134. [
55. Williams, L. (2009). Amerigo's Copper/Moly Output from El Teniente Tailings Reaching NewRecords.Retrieved,2011,fromhttp://www.mineweb.com/mineweb/view/mineweb/en/page66?oid=93691&sn=Detail
56. Y. Pontikes, G. N. Angelopoulos, B. Blanpain, "Radioactive elements in Bayer’s process bauxite residue and their impact in valorization options", Transportation of NORM, NORM Measurements and Strategies, Building Materials, Advances in Sci. and Tech, 45, 2176–2181 (2006).
57. Zhu, L.P., Ni, W., Huang, D., Hui, M. and Gao, S.J. (2011), “Whole-tailings backfilling materials with fly ash”, J. Univ. Sci. Technol. Beijing, 33(10), 190-1196.

DOI: 10.31695/IJASRE.2022.8.3.3