Market Viable Products from Mine Tailings

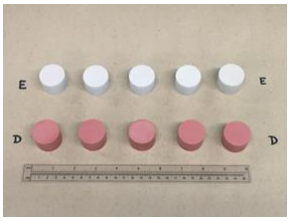
Stefka Ormsby, Freeport-McMoRan Inc., United States
Dan Ramey, Freeport-McMoRan Inc., United States
Tara Hosick, Freeport-McMoRan Inc., United States

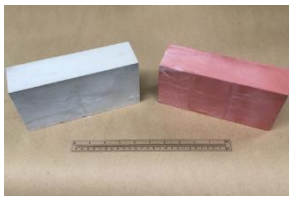
Abstract

Market Viable Products (MVP) will reduce the volume of mine tailings left as a waste behind after copper is extracted from ore. The tailings are initially in the form of slurry along with mine waters at 50% composition by mass. The slurry is deposited at the mine tailing's impoundment and the water is decanted in a pond and reused within the mine process. Utilizing MVPs to reduce the tailing's impoundment could present a solution for lifecycle operation with potential environmental, social, and economic impacts. Multiple MVPs may need to be considered to consume the large volumes of tailings stored in the impoundments.

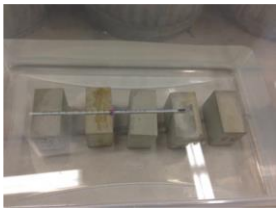
This paper summarizes the studies conducted with Freeport-McMoRan Inc. (Freeport) mine tailings over the last fifteen years. The studies were conducted in collaboration with technology partners as well as using internal resources. Some of the studies listed here are in the proof-of-concept stage while others are completed. The primary goal of these studies was to evaluate the feasibility for making MVP from mine tailings. The products evaluated included bricks, formed products, fiberglass, glass, acid-resistant concrete, aggregate media, ceramic tile, and insulation/coatings materials. The focus for each product is on markets and competition, customer demand, unit cost, percent of tailings utilized within the product, capital/operational cost, and carbon footprint. The goal is to have a clear understanding of the end applications and pro/cons associated with each product. At the end of the study all products will be ranked in terms of potential and suggest future implementation to reduce tailings inventories and associated liabilities. Each mine site has deposited tailings that could be utilized for MVP, if successful.

Formed Products: Sixty tons of Sierrita tailings were used to produce a large batch of bricks in Germany. The bricks were steam cured with sand-lime composition. Four different element sizes were produced. Efflorescence of alkali salts was observed on some of the brick surfaces. Additional measures might be required such as coatings, plasters, and paints if the bricks are exposed to contact with water. The bricks were excellent for noise and heat insulation. In addition, the unit cost of manufacturing of the bricks was competitive with clay bricks and cinder bricks. These Sierrita bricks are used at the Freeport corporate office as a decorative material in elevator banks. Picture of the bricks are shown.





Brixx: The brixx study was conducted by Pittsburgh Minerals and Environmental Technology (PMET) as a technology partner. Tailings material from the Sierrita, Henderson, Climax, and Grasberg Mines were used at different times over the last 15 years. A small batch demonstration project produced bricks in various colors. PMET patent technology was used to convert the tailings into bricks. In general, the process was comprised of two phases. In Phase I, tailings characterisation and small-scale sample prep took place. The small samples consisted of mixing lime, water and tailings to uniform slurry and then pressing the mixture to form shapes at forming pressure of 5,000psi, 7,500psi and 10,000psi. The shape was then cured in an autoclave for 6 to 8 hours with saturated steam. Full scale products were made in Phase II. The produced formed product met the ASTM C-73 properties for severe application and the Toxicity Characteristics Leaching Procedure (TCLP) for leaching of RCRA metals. Some of the parameters evaluated in the study were: tailings mineralogy, matrix of various mixes, mechanical properties, water absorption, TCLP analysis, and financial evaluation for full scale production. The operating cost of production was favorable. Capital cost was not estimated. Approximately 7 lbs of tailings will be consumed for each brick.



Geopolymer: The study was conducted in 2013 with The University of Arizona, Civil Engineering Department as technology partner. Freeport tailings from the Sierrita mine were provided for the proof-of-concept phase. Batch scale tests were conducted to produce formed product based on geopolymerazation. In addition, aluminium sludge was also provided from the mine site and added to adjust Si/Al and Na/Al ratios and enhance the geopolymerization process. Aluminium sludge was produced in High Density Sludge (HDS) water treatment process evaluation as part of the mine for closure study. A matrix using different compositions was used to achieve the optimum mixture. The effects of different factors including activator concentration, water/solid ratio, and curing time and temperature on

compressive strength, water absorption, durability (freeze/thaw), and environmental feasibility were studied. The product passed TCLP analysis as part of the environmental evaluation.

Batch scale tests produced 30 bricks that met the American Society for Testing and Materials (ASTM) standards. Moreover, commercial evaluation for 6 million bricks per year plant production was conducted with total capital and operating cost of $2.66Million. The sales price per brick was $0.50 and was competitive with other formed products during the 2013 evaluation.

Acid Resistant Concrete: This study is in the proof-of-concept phase at The University of Arizona, Civil Engineering Department as technology partner. The objective is to develop a method for producing acid resistant concrete from mine tailings and aluminium sludge by using the innovative geopolymerazation technology. Different solutions will be used as the activator under different conditions. A matrix using various parameters will be developed to outline the optimum mixture. After the "recipe" is developed, technical and economic analyses will be performed for the MVP.

Insulation/Fillers: This study is to be conducted with the Arizona State University (ASU) as Freeport's technology partner specifically, the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG). Series of laboratory-scale tests will be conducted to evaluate the potential for combinations of mine tailings and binder-forming additives selected by CBBG to achieve desirable fresh and hardened properties of cementitious materials. The materials will be used in applications including coatings or sprays, grouts, and "just-add-water" products. The objective is to maximize the percent of tailings used in the product. Specific properties will be evaluated for coatings and sprays, as well as grouts/mortars. A matrix will be developed with additives at different percent to achieve the desired properties. In addition, field-scale tests will be developed as well as verification/validation studies for materials belonging to the coatings and grout/mortar classes. Tailings from two different mine sites were initially screened for the study and deemed feasible.

Ceramic Tiles: Series of testwork will be conducted by our technology partner, IntoCeramics, to produce ceramic tiles from tailings. This will be a proof-of-concept study using Freeport mine tailings, but the technology is somewhat established with a variety of waste products used as feed source by IntoCeramics in the past. The feed material will be evaluated to determine the process characteristics. The next step will focus on forming five 4in x 4in ceramic tiles. Other raw materials will be added to achieve the desired characteristics. The sample will then go through series of processing steps such as heating, cooling, and annealing as deemed necessary. The physical properties of the ceramic tiles will be tested for strength-Modulus of Rupture (MOR), water absorption, and TCLP leaching for the RCRA 8 metals. Other shapes and products could be considered, if feasible.

Fiberglass: The scope of this study is to produce fiberglass from tailings and is conducted by Nomad Fabrication LLC under a non-disclosure agreement. In phase one, the study will focus on the proof-of-

concept where glasses will be produced from silicas and alumina directly as fiberglass alternatives or composited with cured resins. This phase will capture tailings characterization, thermal evaluation, formulation of the "recipe" and the business case for the specific recipe. This would be considered the base case. If successful, a bench top test and full-scale plant production will follow. The concept is to grade the end-result glass filaments and introduce those to commercial supply chains, as well as investigate premise-fabrication to manufacture roving, matting or chopped products. The study will evaluate a matrix to be used in creating the "recipe" with wider spectrum of commercial applications. The "recipe" will be tested in its flexibility for production of MVPs, with some products reaching the mass consumer but others having specialty applications. The goal is to determine the limiting ingredients and their cut-off range for MVP production. At present, the study is conducted at an external facility with the option to be moved in-house.

Glass: The goal of this study is to make glass from tailings. The scope of work is being formulated for proof-of-concept. The process flow diagram is in development and is being evaluated in-house with major process steps as melting, spinning, shaping, cooling, testing, and packing. A wide range of MVPs could be made based on the specifications and end applications. The tailings sample used for the study was from the Henderson mine and contained 58% quartz (SiO2). Eight grades with commercially available glass fibers are available ranging from 52% to 75% quartz. Each grade corresponds to a different application with the most widely used type having 63% to 72% quartz (Type-A). Other grades such as S grade and AR glass will have a higher market price but must have 0-18% of ZrO2. Recycled glass, such as cullet can be used to enhance the quartz % in the feed. Other ingredients are required to change the physical, chemical, and mechanical properties of the final product for specific applications. Due to the COVID 19 pandemic, the current glass production had decreased but it is expected to reach over $150 billion in 2024.

Sandblasting Media: This study is conducted by US Minerals and it is in the initial screening phase of characterization of physical properties. The goal is to use tailings material as feed to produce aggregate blasting media. Tailings from two different mine sites were provided for the evaluation and the results are pending. Potential end applications for the media are in steel fabrication, offshore oil drilling, blasting, and painting contractors, ship building and repair, petrochemical, and refining contractors. At present, US Minerals is producing a variety of grades and aggregate materials as coal slag, iron silicate (copper slag) and specialty abrasives.

If the MVPs are successful, the value addition will have a major economic, social, and environmental impact not just for Freeport-McMoRan but for the global mining industry as well. This "cradle to grave" approach will drive the leading edge of innovation and positive global prospective for the mining industry.