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INNOVATIONS APPLIED IN TAILING DAMS

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ABSTRACT

Brazil lived in less than five years, two huge accidents with mining tailings dams in the cities of Mariana and Brumadinho – Minas Gerais State. Brumadinho's accident is considered the biggest world disaster with dams in the last 35 years, and has entered the statistics as the biggest work accident in Brazilian history. The scenario of these tragedies begins with the negligence of companies with the treatment and disposal of waste. They invest in technologies for the processing of ore and put aside the tailings. The amount of tailings generated in the mineral processing is high, often equal to or greater than the amount of raw ore produced. The work had as objective to make a search in two bases of patents on innovation or application of new technologies in tailings dams, or new technologies for the replacement of dams. The results of the research showed that worldwide efforts have been made in the following research fronts: use of the tailings as a raw material for the creation of other products, increase in the drying capacity of the tailings for subsequent deposit in the dams (dry stacking), modern techniques of inspection of structures and the accumulation of tailings in the deposits.

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INTRODUCTION

Mining in Brazil attracts many investments and generates great financial return due to the visibility that the sector has historically enjoyed. The extraction of minerals is associated with social phenomena and is linked to the country's growth and development issues. In 2021, metallic substances accounted for about 80% of the total value of Brazilian mineral production. Among these substances, eleven stand out: aluminum, copper, chromium, tin, iron, manganese, niobium, nickel, gold, vanadium and zinc. The production value of these eleven substances totaled 193,5 billion reais, highlighting the significant participation of iron in this amount, whose production is mainly concentrated in the states of Pará and Minas Gerais (Brazilian Mineral Yearbook, 2021). The Brazilian mineral industry, formed by the business segments of exploration (research and prospecting), mining and mineral transformation, comprises approximately ten thousand companies, most of them micro and small groups. It currently employs 2 million people, accounting for 4.2% of the national GDP and 30% of the positive balance of the trade balance, occupying only 0.5% of our territory (Alves, 2019). In addition, mining promoted the migration of workers to the interior of the country, increasing the occupation of the interior of our territory.

The amount of tailings generated in mineral processing processes is often equal to or greater than the amount of raw ore produced. Data from the 2020 Brazilian Mineral Yearbook show that the average percentage of tailings produced in Brazil was higher than the gross amount of ore produced for the following substances: aluminum, copper, chromium, manganese, nickel and zinc. In the case of iron and aluminum ores, the amount of tailings generated was 35.67% and 46.62%, respectively, in relation to the gross amount of ore produced (Brazilian Mineral Yearbook, 2021). The ores extracted from the mining fields become products, which over time are consumed by humanity. However, the entire volume of waste produced does not have the same destination. This tailings needs a place with large storage capacity (large storage volumes). This causes a big problem for the mining industry, since this material needs to be stored for later use (when possible), without harming the environment. According to Vale (2021), tailings dams are structures used as reservoirs for the containment and accumulation of liquid substances or mixtures of liquids and solids from the mineral processing process. These structures are considered the most economically viable means for the disposal of tailings, since they are built in less time, and can use the material to be disposed of (Soares, 2010; Souza Junior *et al.,* 2018). The mining industry lives the paradigm of maintaining production standards with the generation of a minimum amount of waste.

Geological knowledge, compliance with mine planning and a good exploration project can positively affect the generation of tailings (Instituto Brasileiro de Mineração IBRAM, 2016). It has become clear in recent years that in Brazil there is little investment in inspection of dams, and that, even with a large number of previous accidents, the authorities continued to leave the inspection of their own structures to the companies themselves. As a result, we have witnessed two of the world's greatest tragedies, both in environmental impact and in the number of deaths (Lacaz *et al*., 2017; Borges, 2018; Gomes *et al*., 2019; Silva *et al*., 2019; Sznelwar *et al*., 2019; Silva *et al*., 2020). There is information in literature and audiovisual media about the supervisory role of the State and its responsibilities, however, will it be technologically possible to prevent these structures from collapsing?. The use of tailings by companies instead of throwing them in dams, the low investment in equipment and monitoring systems, the improvement of their production processes, should also be considered as major failures of the companies, which can lead to a great risk of accidents, with the population being victimized by the catastrophic failures of such an undertaking. Papers described in the literature propose the reuse of waste from ore processing in order to remove them from dams (Rocha, 2009; Costa *et al*., 2014; Fontes *et al*., 2018). Some published researches describe solutions to be implemented in the dam itself to increase its safety. Among these, we can highlight the use of techniques already known by engineering, which have been applied and improved in other areas and may appear as technologies applied to tailings dams (Almeida *et al*., 2005; Resende *et al*., 2013; Martini *et al*., 2016). This paper has the objective of making a search in two patent bases on innovation and application of new technologies in tailings dams. The study shows that many innovative techniques can be used to increase the safety of dams and even provide artifices so that they are no longer the main current concern. The results of this research may show which paths companies/researchers are proposing in relation to the safety of tailings dams in order to prevent further tragedies from happening.

MATERIALS AND METHODS

INPI (National Institute of Industrial Property). Exchange intellectual by industrial. The keywords “dam” and “tailings” were used and the results were analyzed. All results were transferred to Excel to be sorted and filtered, using advanced filters, according to the research interest.

Derwent International Database: Derwent is the most complete and up-to-date international patent database available today. Provides Internet access to more than 30 million inventions described in more than 65 million patent documents. Includes links to cited patents, cited articles, and full-text patent data sources. The Derwent database search was performed by accessing the CAPES journal portal. The keywords used were “tailing dam” (tailing dam) applied to the abstract.

RESULTS AND DISCUSSION

Part 1: INPI Patent Base Search. The survey returned 417 results, which were filtered in order to analyze only patents related to the safety issue in mining tailings dams. The initial filtering performed on the returned results showed 82 patents. After analyzing all the results obtained in the search and rejecting the results that were not considered relevant to the research, a list with 59 patents remained. Of these, seven did not have documents attached for analysis, being excluded from the research. A new filtering was done with the remaining 52 results, and after analyzing these documents, a total of 31 results were excluded. Table 1 shows the 21 patents obtained as a result of the search related to the study after data processing. Some of the patents described in Table 1 were considered as most relevant to the research and will be described in the article.

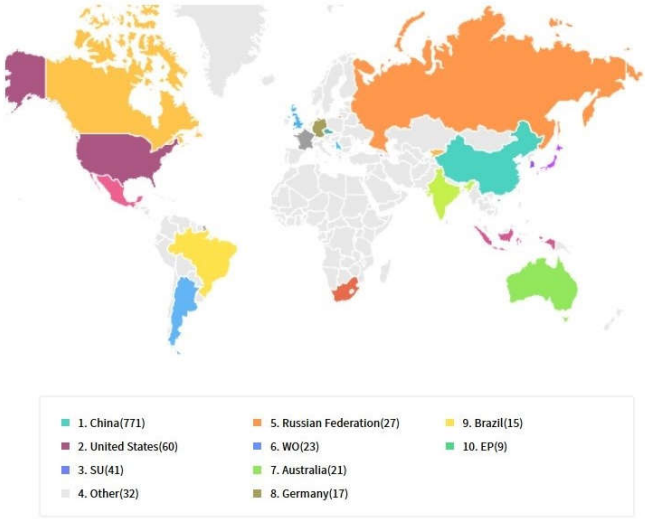

Figure 1. Main patent applicant countries on tailings dams (Derwent Database)

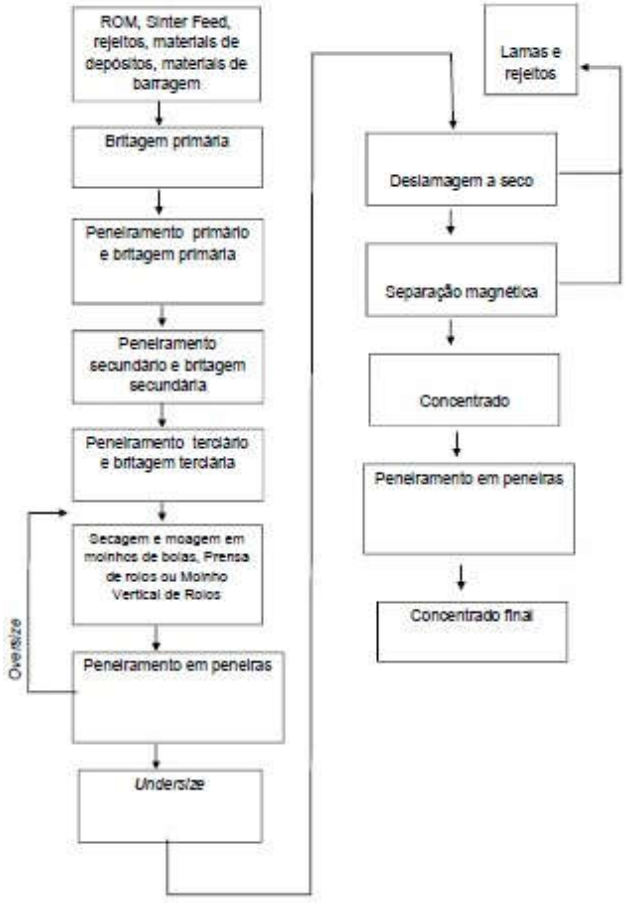

Figure 2. Flowchart of the dry process (Patent: AU2013334500, 2014)

Patent: BR 10 2017 018466 8 (2017). Title: Water damming system using mining tailings and bagwall use. The procedure proposed in the patent aims to take advantage of mining tailings in most or all of it, in order to transform an environmental liability stored in dams into a structure that can improve the relief and contribute to the sustainable development of the region affected by mining , reducing the cost of transporting tailings, enabling the expansion of the production market and application of co-products, as well as the prevention of new dam failures, erosion and flood control, water availability and generation of employment and income associated with a better scenario of water availability, such as: energy generation, irrigated agriculture, fish farming, tourism, among others.

Table 1. Results of searches in the INPI database after data processing

Request	Title
BR 10 2017 018466 8	Water damming system using mining tailings and bagwall use
BR 10 2017 010715 9	Process for hauling mining tailings
BR 10 2016 017627 1	Process for treatment of tailings/mining waste
BR 10 2015 017233 8	Method and system for determining soil characteristics in ore tailings deposition areas and tailings deposition method in mining
BR 10 2016 007116 0	Tailingsdam stabilization process
PI 0403981-5	Process for reducingthe volume oftailings in containmentdamsusing a thermaltorchatdepth
BR 10 2014 025420 0	Process and system for dry processing of iron oxide ore fines and superfines through a magnetic separation unit
BR 10 2014 009451 2	Drymagneticprocess for concentrating ore fines
BR 10 2014 016591 6	Process for separatingsandfromsludgefrom iron ore fine tailings
BR 10 2014 000832 2	Productionof normal sandusing mining residues
PI 0716028-3	Porousmembraneproducedfrom a vinylidenefluorideresinandmethod for preparingthesame
PI 9300779-5	Filter medium consisting of a mixture of oxidized manganese ore and siliceoustailings from the concentration of ores, for the treatment of public and industrial water supplies
BR 10 2012 016339 0	Process methodology for dry iron ore treatment and production
BR 10 2012 008340 0	Processand system for dryrecoveryof iron oxide ore fines and super fines
BR 10 2016 014718 2	Flexible coating obtained from the use of mining tailings
PI 0913960-5	Method for treating ore tailings
BR 10 2014 032639 1	Mobile plant for magnetic separation of minerals and tailings
PI 0602236-7	Dewatering process for tailings from wet ore processing
PI 9701708-6	Process of disaggregation or disunity of particles with different physical and/or chemical properties, constituents of an aggregate of mineralogical nature, by-products or industrial or metallurgical waste
BR 10 2013 031260 6	Use of tailings from iron ore dams as raw material for the construction of road infrastructure
PI 0803327-7	Iron ore concentration process by magnetic separation with low water consumption and little tailings sludge generation

Table 2. Patents and abstracts obtained from the Derwent database search

Patent Number	Title
AU2013334500A1	Iron ore concentration process with a grinding circuit, drydesliming and dryormixed concentration (dry and wet)
AU199735330	Soiltreatmentmethod
CN101591901A	A method for constructing a metallurgical industry gangue storage dam
CN102410834A	Three-dimensional laser scan of the rear dam body dynamic monitoring device
CN104181606A	A mine management method based on new radar and sensor technology
CN109146876A	A method of detection of mine environment change based on remote sensing image
CN109311027A	Reduce the need for tailings storage dam in mineral flotation
CN110586315A	A dry iron ore selection method

The patent proposes the use of geotextiles for making large bags that would be filled with waste pulp. After the period of drainage and the total dewatering of the material inside the geofabric, the material compacts and can be used as structural reinforcement both in the dams themselves and in works to contain slopes, filling in exhausted pits, breakwaters, diversions of rivers, among other applications. In terms of composition, geotextiles are made of textile fibers of natural or chemical types. Synthetic polymer fibers are the most used: PET (polyester), PA (polyamide), PE (polyethylene), and others (Ferreira Gomes, 2001). The fibers of these materials are interwoven and acquire a textile, flat and linear format, which are used according to the following purposes. The main purpose required by geotextiles is filtering. As bagwalls are supplied with tailings pulp, the particles are retained by the fabric that traps the solid and releases water, promoting dewatering. A feature of the geofabric is its ability to have its permeability for only one of its sides, having its back a shape that does not allow the passage of water.

Patent: BR 10 2017 010715 9 (2017). Title: Process for hauling mining tailings. The present invention deals with a process for the environmental management of tailings, particularly for transporting tailings from the mining industry to a disposal site. Mining tailings are commonly composed of silica and clay, among other solid particles, suspended in water. The process includes an initial stage of drying the mining tailings to recover water while the tailings are located near the mining plant. The subsequent steps are: foaming with biodegradable surfactant and water; mixing the dry tailings with the foam; and loading the foam mixture and dry tailings to the disposal site by means of a pumping system comprising a plurality of ducts with at least one pump. The mixture of foam and dry tailings can be launched directly at the disposal site or mixed with cement or silica fume to be used in the filling of pits, dams or highlights in the mining field, or for other purposes, such as making blocks for civil construction, recycled aggregates and pavement sub-base, among others. This inventiondeals with techniques for the use of natural resources used in a more rationalway in order to reduce water consumption, bringing savings, reduction of environmental impactand risks to dams that the accumulation of water in the tailings can provide. To move large volumes of increasingly finer tailings, a fluid medium is used to transport the tailings through pipes, from its origin to the tailings dam. As the volume of tailings generated is very large and constantly produced, it is common to use pipes that directly dispose of this material in the tailing dams. Thinking about reducing the water consumption needed to transport the waste pulp to its destination, the inventor chose to use a biodegradable surfactant to generate foam, which would be the means responsible for carrying the particulate material, inside the pipes, until your destiny. Once released into the dam, the foam breaks up and the ore particles settle to the bottom more quickly. In addition to using a smaller volume of water, a smaller area of beach and settling pond would be formed, since there would be less water carried along with the pulp. With the use of a "biodegradable" surfactant, this chemical compound will be in tailings dams exposed to the climate and the action of microorganisms present in this environment can cause its deterioration, decomposing all the surfactant and leaving only the ore.

Patent: BR 102015017233-8 (2015). Title: Method and system for determining soil characteristics in ore tailings deposition areas and tailings deposition method in mining. The present invention employs a geophysical technique called Ground Penetrating Radar or GPR for determining soil characteristics and defining the existence of sedimentation patterns in ore tailings deposition sites (Martini, 2014).

GPR or geo radar is a geophysical, non-destructive surface assessment method that uses high frequency electromagnetic waves (usually between 10 and 2500 MHz) to map structures, rock differences or buried objects. The mostused electromagnetic method in the field of geotechnics. Although GPR is a widely used technique in geophysics, its application for investigating the bed of tailings dams has been little studied. The patent presented establishes a methodology and application of the GPR system as a tool for controlling and evaluating the volume of accumulation and sedimentation rate in a given area, the deposition pattern and possible voids at points of accumulation of load efforts, deposition of different terrains, more or less clayey or sandy and rocky. This is done in a non-invasive way, not requiring the drilling of underground layers to assess the soil layers. The non-intrusive study, in a soil that needs to be preserved as stable as possible, brings benefits such as safety to operations, better soil dewatering and more efficient use of dam heightening.

Patent: BR 10 2016 007116 0 (2016). Title: Process for stabilizing a tailings dam. The present application for the privilege of invention intends to solve the problem of drowning drains in tailings dams with a stabilizing drain system, through synthetic drains associated with the application of vacuum, which enhances the effect of reducing pore pressures and consolidation by reducing the index of soil voids, in the short term. Instead of downstream soil saturation could stabilize it with the proposed system. In a tailings dam there must necessarily be drains for the removal of water accumulated in the various levels of the structure. With the growth of the barrier, the weight of the ore itself, can mainly cause liquefaction effects, which can cause the dam to rupture. Such drainage is currently done with the use of vertical drains applied through perforations in buildings. According to the inventor, such drainage is not effective and he suggests a system capable of solving the problems of this type of drainage. Clogging consists of the process of obstructing a draining water flow, by ultrafine particles, sedimented inside the drains, in the geotextile voids, or in other water collection channels, which, with prolonged time, are deposited in certain points of the causing obstructions in the water passages. In geotextiles, this effect can be reduced by applying a layer of sandy soil over the fabric, before it receives a clayey soil. Clay soil particles, because they are very fine, obstruct the passage of water through the geosynthetic pores, preventing drainage from occurring. Although, by definition, clogging originates from the deposition of ultra-fine materials from the iron ores themselves, it is also known that the presence of iron-bacteria or other types of bacterial colonies can cause the clogging of drains and, therefore, start a process of water accumulation inside the tailings mass, still in the dams. Therefore, the patent seeks to solve the problem of clogging such drains, proposing a stabilizing drain system using synthetic drains associated with the application of vacuum to enhance the pore pressure reduction effect and stimulate consolidation by reducing the void rate of soil in the short term.

Part 2: Derwent Database. In relation to patent applications with the theme of tailings dam, Figure 1 (DerwentDatabase) shows the main applicant countries worldwide. It can be seen that Brazil ranks ninth among the world filing countries and China is the country with the highest number of patents filed on the tailings dam theme. The research was carried out with the keywords “tailing dam” in the abstract, with 1076 results being obtained. A treatment of these data was made, excluding patents that were not the objective of the research, as well as duplicate results. After the initial treatment of the data, 30 results remained. Of these, a part indicated patents containing construction methods for new dams with characteristics of civil engineering projects. These results were excluded, having at the end of the research a total of 11 results that applied to new technologies applied to dam safety. Table 2 shows the most relevant patents. Below is a breakdown of some patents found in the research. Patent: AU199735330A (1998). Title: Soil treatment method. The present invention relates to a method of treating a volume of soil for the purpose of rendering the volume or area of soil impermeable to water. Toxic substances present in the soil typically arise from the dumping or burial of waste material in the soil.

Toxic substances include those that form from the leaching of toxic substances from tailings in the mineral industry. The present invention seeks to overcome or minimize this problem. According to the invention there is provided a method of making a volume of soil substantially impermeable to water which comprises applying to the soil a water-soluble calcium salt (calcium acetate) or a mixture of calcium acetate with a gelling agent such as agar with aqueous sodium silicate solution. The mentioned patent seeks, through known chemical reactions, to vitrify the soil and make it less susceptible to infiltration. The incorporation has particular application in circumstances where it is desired to form the dam bed. The patent also presents alternatives for the treatment of dams or dams that are already leaking, or have a high permeability of their bed. Incorporation comprises spraying over the area of soil to be treated with a sufficient amount of calcium acetate solution to allow the calcium acetate solution to soak and penetrate the topsoil. If desired, a suitable wetting agent can be added to the solution to ensure adequate absorption of the solution into the soil. After treating the topsoil a sodium silicate solution is then sprayed onto the surface in sufficient quantity to react with the calcium acetate solution to form a water-impermeable layer and again, if desired, a suitable wetting agent can be added to the solution to ensure adequate absorption of the solution into the soil. If desired the treatment process may require several sequential applications of the calcium and silicate solutions. In circumstances where contaminants are contained in a layer of soil it may be appropriate to initially treat a layer of soil below the contaminants and to each side of the contamination area in order to contain the contaminants within the defined area and prevent further propagation of these contaminants. The combination of the three components aims to associate their main characteristics: stability, gelling and sealant which, when introduced to the bottom of a settling lake, can be effective in reducing water infiltration in regions with potential for damage. Lesser concentration of efforts, from the effects of erosion caused by water, could reduce the risk of dam collapse or contamination of the soil below it.

Patent: AU2013334500 (2014). Title: System and process for dry ore concentration. The patent shows two main approaches with the objective that, in the near future, the problems and impacts caused by tailings dams can be eliminated. The main approaches consist of: non-use or reduction of water consumption in mining; increasing use of ores (fine and/or superfine) in the production of steel or other products. The invention aims to reduce water consumption in mining, while trying to make the tailings more concentrated in iron, thus being able to be used in industry. Although the concentration of iron ore by magnetic concentration is not new, this patent presents a more economical and faster way that can make dry mining more profitable. Furthermore, with dry production, the accumulation of water in the dams would no longer pose a risk to society. Flotation is the most used method of concentration of iron ore. This process requires a desliming stage, that is, the extraction of fines and ultrafines from large volumes of water generated during milling, as well as the final storage of the unused material for the tailing dams. This process is the generator of much of the super fine tailings and has caused devastating potential when these dams fail. They are fine, clayey tailings, which are hardly used and which have a very high potential to liquefy. This makes large tailings dams, resulting from decades of mining, potentially dangerous and catastrophic. Dry production techniques have been studied, including dry magnetic concentration to replace flotation. The patent seeks to provide a system for dry concentration that eliminates the need for equipment used in wet processing such as pneumatic classifiers and mug conveyors, making the process economically viable. Figure 2 shows a patent flow diagram that exemplifies the inventors' dry concentration process. The Flowchart shows at least one step of dry grinding the ore. The dry milling step can be done in ball mills, roller press or vertical roller mill. Before the grinding step, two or three steps of crushing and screening in natural moisture are carried out before the ore grinding step. Crushing in natural moisture can be done in gyratory, conical, conventional impact crushers or vertical shaft impact vibrators. After the milling step, at least one dry grading step is provided. This classification step is carried out using conventional or high frequency

sieves (which vibrate at least 3600 RPM). After these steps, the replacement of the flotation concentration by the dry magnetic concentration occurs, which can be carried out in drum or roller concentrators. Optionally, after the magnetic separation step, an additional dry classification step can be carried out with high frequency sieves. This additional classification step aims to remove the quartz fraction present in the coarse fraction, improving the final quality of the product, obtaining a final concentrate of greater purity.

Patent: CN102410834 (2012). Title: Dynamic device for three-dimensional laser scanning and monitoring of the dam body. The purpose of the patent is the automatic response in cases ofdamslope slides orthepartialor total breaking of physical barriers to the mining industry' stailings. The patent uses the automation of three-dimensional mapping devices that, combined with artificial intelligence and algorithms for calculating faults and slip tolerances, automatically trigger contingency plans for government, business and communities immediately affected by accidents in such structures. The patent proposes the use of a three-dimensional laser scanning device for dynamic monitoring of the tailings dam body. The patent makes it clear that the innovation is not in 3D scanner equipment, but in decision-making algorithms based on artificial intelligence. Such algorithms are capable of coordinating the frequency of scans, a more detailed assessment of doubtful regions or even automatically triggering emergency evacuation alarms and accident reports. 3D Laser Scanning is a technology that uses three-dimensional laser scanning equipment (Laser Scanner), a device that analyzes a real-world object or environment to gather precise data about its shape and appearance. The collected data canbeusedto build three-dimensional digital models andhave a widevarietyofapplications. To implement a monitoring system based on 3D scanning, in addition to equipment with very high resolution and performance, it is necessary to improve the treatment of images. To be efficient, it needs to focus on the entire dam slope. Therefore, it must be at a considerable distance, otherwise it would not be possible to scan the entire barrier.

CONCLUSION

In recent years, Brazil has witnessed two major accidents with the failure of tailings dams, which resulted in a tragedy that affected entire cities with a large number of deaths, homeless people, environmental damage and others. The research resulted in a great knowledge of recent innovations and application of techniques to increase safety in tailings dams, which shows a world wide interest in improvingthe use of these structures Recent research has shown how much progress we still need to make in order to have a better tailings management, how we can use it as a raw material, the importance of monitoring tailings in order to keep these stocks intact for longer and the paths that researchers are developing for a greater safety in the operation of dams today.

In relation to researched patents, Brazil ranks ninth in the number of patent applications filed for the development of industrial solutions and applications in technological challenges of mining in relation to other countries. China stands out in terms of new patent filings in the mineral area, which may be related to its prominent place among the world's major iron ore producers, and consequently, tailings generators. The results of this research showed that most of the analyzed patents deal with the use of the dam's tailings for some purpose. Another part of the patents propose new technologies or the application of existing technologies in other areas for monitoring the dam in the field. Worldwide efforts have been made in the following research fronts: use of tailings as a raw material for the creation of other products, increase in the drying capacity of tailings for subsequent deposit in dams (dry stacking), modern techniques for inspecting structures and accumulation of tailings in the deposits.

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