CRITICAL REVIEW OF INDUSTRIAL SOLID WASTES AS BARRIER MATERIAL FOR IMPERMEABILIZATION OF STORAGE WASTE FACILITIES

Leonardo Marchiori [1] and António Albuquerque [2]

[1] *GeoBioTec, Department of Civil Engineering, Universidade da Beira Interior – Calçada Fonte do Lameiro 6, 6200-358, Covilhã, Portugal*
[2] *Department of Civil Engineering, Universidade da Beira Interior, Covilhã, Portugal*

ABSTRACT: Natural materials (e.g. clays) and synthetic materials (e.g. geosynthetics) are commonly applied as low hydraulic conductivity layers and environmental protection barriers in civil engineering works for storing solid wastes and wastewaters (e.g. solid waste landfilling, wastewater lagoons and mining waste ponds) for both covering and bottom impermeabilization of soils structures (Booker et al., 1997; Massad, 2010). However, due to a future shortage of clay materials and their high transport costs, in addition to geosynthetics generating more waste and presenting high costs, two needs emerge: reducing the amount of waste generated and developing strategies for preventing this waste from infiltrating the soil and ground water. One of the possible solutions consists in the use of some geotechnically applicable residues to prevent soil infiltration. Thus, according to (D. A. Rubinos & Spagnoli, 2018) the use of waste materials is particularly advantageous since it can considerably reduce construction costs, help preserve natural resources, and contribute to sustainability by turning “waste” materials into “valuable resource”. Many by-products of industry and waste (fly and bottom coal ash, blast furnace slag, foundry sands, water treatment plant sludge, agroindustry ashes, incinerated biomass ash, red mud, drilling mud and mine waste, among others) have been extensively studied as to their suitability as a geomaterial (Kumar et al., 2019) and showed promising results for use in waterproofing barriers (liners). The most significant factors that depend on hydraulic conductivity are index properties, compaction characteristics and compressive strength, so, in this aspect, hydraulic, mechanical, physical-chemical and mineralogical properties determine the valorisation, or not, of the waste as liner material. Industrial wastes and geocomposites acting as hydraulic barriers material literature were reviewed and analysed its actual applications such as lack of researches suggesting future investigations.

Keywords: industrial waste(s) valoris(z)ation; waste material(s); hydraulic barrier(s); waterproofing; control of pollutant(s) leaching; environmental sealing; earthwork(s).

1. INTRODUCTION

Waste is any substance or object that the holder discards or has the intention or obligation to discard (European Parliament and of the Council, 2008) and the so-called industrial waste is that produced by any industrial activity such as mining operations, water treatment, thermal processes, plants, industries and factories of all products. Solid and semi-solid waste from water, effluent and industrial treatment facilities are called waste from the treatment plant. The remaining materials from the combustion of wood, coal and other combustible residues are classified as ash and residues (Tchobanoglous et al., 1993). Since the United Nations Conference on the Human Environment in 1972, known as the Stockholm Conference, the United Nations (UN) has been designing and planning initiatives around the preservation of the environment. With the organization of ECO-92, also known as Rio-92, which used the first report as a basis, the reuse and recycling of waste has become a national and global problem. The initial thinking on the topic involves some main applications, such as direct reuse, raw materials for remanufacturing and reprocessing, to produce biological and chemical conversion products, fuel source and land reclamation. There was a change in society's attitudes, resulting in a strong interest in the development of beneficial reuse markets for industrial by-products (Abichou et al., 1998). Many industrial wastes, such as blast furnace and boiler slag, fly and botton coal ash wasted and other materials have been used as road construction materials and this market continues to grow due to its great performance and financial numbers. In view of this possible and viable application, started to investigate the rejected products for other applications in civil engineering.

A potential for the valorization of industrial waste is the application of some of them as barrier materials for waterproofing earthworks for the storage of solid waste (SW) and wastewater. However, for this application, one must study its physical, chemical and mineralogical properties, in addition to conducting characterization, mechanical and leaching experiments, proving the low conductivity, hydraulic and compaction resistance. Important physical characteristics include specific weight, moisture content, particle size and size distribution, field capacity and compacted porosity of residues, chemical properties are close analyzes, ash melting point, final analysis (main elements) and energy content and biological properties, as if they are biodegradable, organic, odors are produced, attracting groups of animals (Tchobanoglous et al., 1993). They are applicable to all types of solid waste, even industrial waste. The identification of appropriate geo-applications for an industrial waste is the most crucial step, requiring consideration of its properties and a comprehensive knowledge and understanding of geotechnical construction, in addition to economic and environmental regulations (Abichou et al., 1998).

Natural materials (clays) and synthetic materials (geosynthetics) are commonly applied as layers of low hydraulic conductivity and environmental protection barriers in civil engineering works to store solid waste and wastewater (eg solid waste landfill, wastewater ponds and mining ponds) for both roofing and waterproofing the bottom of soil structures (Abichou, Tarek; Benson, Craig H.; Edil, 2000; Abichou et al., 1998, 2002; Agamuthu, 2013; Devarangadi, Manikanta, Shankar, 2020; Fall et al., 2009; Guney et al., 2014; Kraus et al., 1997; Osinubi & Eberemu, 2010; Palmer et al., 2000; D. Rubinos et al., 2015; D. A. Rubinos & Spagnoli, 2018; Tsugawa et al., 2017). Landfill sealing technologies comprise layers of low hydraulic conductivity designed as part of lower roofs and coverings, for which clays and geosynthetic materials are conventionally used (D. A. Rubinos & Spagnoli, 2018). The basal linings of landfills are generally built with natural clay soils, due to their characteristics of high strength and low hydraulic conductivity. However, in recent years, it is increasingly difficult to find locally available clay soils that satisfy the necessary engineering properties (Guney et al., 2014).

Therefore, some of the clay's natural resources, such as bentonite, are decreasing and, therefore, mining companies are now actively looking for new exploitable deposits, while old mines are being reopened and others are closing because of reduced extractions. A good example is the Drakelands Mine, formally known as Hemerdon Mine, located 11 km northeast of Plymouth, England; the mine had been out of operation since 1944, reopened in 2014, but stopped activities in 2018, as the mine was never able to reach the extraction goals, hence financial goals. In addition, a number of solid industrial wastes (for example, heat treatment fly ash, sludge from water treatment plants, ash from biomass incineration plants, sludge from paper mills and sludge from mining operations) that appear to have physical and chemical characteristics similar to clays and continue to be discarded in soils, water or landfills, contributing to significant negative environmental impacts and not being recycled or recovered (Agamuthu, 2013).

An important approach is that, with the increased use of energy and consumption of fossil resources, as well as the generation of waste, which are alternative materials and potential energy resources, it is necessary to manage energy, waste and the environment that seeks maximum efficiency with minimal costs, waste and environmental impacts. Many countries and entities are aware of this situation and strongly value waste disposal. Large volumes of solid industrial by-products are generated each year by industries, and most are landfilled as solid waste at considerable cost (Abichou et al., 1998). There are many reasons given for studying and investigating other uses for this large amount of industrial waste, whether in the interest of industries, giving a cheaper destination to construction companies, to use cheaper raw materials or to the government to solve a big problem, the excess of waste.

2. INDUSTRIAL WASTES

2.1 Hydraulic Barriers

Clays are aluminum silicates, when well compacted have low hydraulic conductivity and they are abundant in nature for the extraction making it proper and relatively cheap for engineering earthworks, principally acting as barriers. Hydraulic conductivity is the most significant factor of soil liner performance. Liners are usually made of compacted soils, commonly clays, and the compaction have important role in determining the hydraulic conductivity and normally it’s value for compacted liner must be less than or equal to $1 _x 10^{-9}$ m/s (Khalid et al., 2019). And geosynthetics that are used in landfill works, wastewater lagoons and mining ponds, they are classified according to their mesh structure as well as material characterization properties, such as hydraulic coefficient, compatibility with clays, shear strengths, puncture, high temperatures, freeze-thaw cycles, creep. They act like an almost waterproofing membrane, geomembrane, to prevent the migration of liquids and gases (Vertematti, 2015).

The main properties of an ideal barrier system are summarized by (Ganjian et al., 2004):

- Low hydraulic conductivity, less than $1 _x 10^{-7}$ cm/s;
- Enough strength to support the weigh above it, at least 5 N/mm^2;
- Deformation during service without cracking or rupture and self-healing properties.;
- Chemical compatibility and high cation exchange capacity;
- Easy construction and with low cost materials.

However, before analyzing the possible alternative materials for use in geotechnical barriers, it is extremely important to disqualify those that are harmful in such applications, due to a physical, chemical and / or mineralogical incompatibility. Several wastes have been identified as technically suitable for use in landfill barriers, however, it is worth mentioning that some of them also show respect for the leaching of dangerous contaminants that could restrict their practical application in real landfills (D. A. Rubinos & Spagnoli, 2018). The (The European Commission, 2014) classified as hazardous a list of wastes called List of Wastes (LoW), those resulting from exploration, mining, quarry, physical and chemical treatment of minerals (chapter 1 of the LoW), which are generated by acids the processing of sulphide ore, red mud from the production of alumina and the physical and chemical processing of non-metalliferous minerals containing dangerous substances, drilling muds containing oil. Waste from wood processing and the production of panels and furniture, pulp, paper and cardboard (chapter 03 of the LoW) is classified as sawdust, burrs, cuttings, wood, agglomerates and veneers containing dangerous substances, non-halogenated, organochlorine organic wood organometallic or inorganic preservatives. Also, thermal processes (chapter 10 of the LoW), such as fly ash and boiler dust, co-incineration slag and powders, gas cleaning residues, sludges, cleaning gas residues containing mercury and other chemical contaminats. And those for management facilities, external wastewater treatment plants and the preparation of water intended for human consumption and water for industrial use (chapter 19 of the LoW), such as filter cake, aqueous liquids, solid for gas treatment wates, among other residues with hazardousness.

2.2 Mining wastes

In the mining sector, during the extraction of ores and minerals, residues such as extremely fine particles are rejected by crushing, sorting or processing the raw material and finding ways to reuse this secondary source to reduce the disposal of mine waste is an important number current (Almeida et al., 2020). Physical, chemical and mechanical properties over mining residues are of interest for reuse, mainly low to moderate hydraulic conductivity, low plasticity and the shear strength.

2.2.1 Drilling mud

The drilling process for oil and gas wells generates drilling fluids and drilling piles as waste. Drilling muds, or drilling fluids, are used to assist the drilling process, the fluid phase can be water, synthetic or natural oils, air, gas or a mixture of these components. The sludge is circulated through the drill to lubricate and cool the drill, control the pressures of the forming fluid and assist in transporting the drilling piles to the surface, where the sludge and piles are separated by mechanical means (Onwukwe & Nwakaudu, 2012). This type of waste has the potential to impact the environment. Depending on the material, such as lubricants, sludge and oil and water-based spacers, they can be contaminated with heavy metals, hydrocarbon surfactants, alcohols, inorganic salts, biocides, cement, bentonite, silicone oils, potassium salts or radioactive material.

Onshore and offshore operators used a variety of methods to manage this drilling waste. Due to the presence of bentonites and the hypothesis that, with thermal treatment, these sludges can be used in landfills as cover and base coatings. (Carignan et al., 2007) used a process called thermal desorption, through indirect thermal recovery processes, which provides for the recycling of the liquid hydrocarbon fraction of these drilling mud residues to treat two different drilling muds. A thermally treated drilling mud waste (TTDMW), TTDMW-UK, was collected from the largest existing sealed container of dry material in Halifax, Nova Scotia, and another TTDMW-NS was collected before the field-scale heat treatment, because, At the time of this study, the Nova Scotia drill mud waste heat treatment facility used a different thermal remediation technique than that performed for the TTDMW-UK sample. Based on the results shown, the two TTDMW samples were classified as sandy silt (TTDMW-UK) and silt (TTDMW-NS) by the Unified Soil Classification System. The hydraulic conductivities of the two samples were similar and slightly higher than the value of 1×10^{-7} cm/ s often specified for municipal landfill systems.

2.2.2 Mining Tailings

The tailings are generated from crushed rocks and the process of extracting the desired product from them by a mine processing plant. Chemical, physical and mechanical processes are used to extract the ore extraction and produce waste, usually as sludge. The chemical and physical characteristics of the tailings are in accordance with the extracted ore, but they can also undergo changes due to the chemical processes applied. In short, the processing of the ore is physically reduced by crushing and grinding methods, then chemical concentration processes are applied, such as foam flotation, gravity and magnetic separation, pressure oxidation, bioleaching and others, to extract the ore.

The hydraulic conductivity of mine tailings has been studied by itself or mixed with other components to improve performance. (Bareither & Gorakhki, 2016) tested mixtures of waste and waste-dominated rocks (i.e., GeoWaste) that were created through which the waste rock particles act as inclusions in the tailing's matrix. The hydraulic conductivity of pure tailings varied between 9×10^{-6} and 7×10^{-8} cm/s, while the hydraulic conductivity of GeoWaste varied between 1 × 10^{-4} and 3 × 10^{-8} cm/s. GeoWaste values for k decreased with an increase in effective voltage from 10 to 100 kPa and was comparable to the hydraulic conductivity of pure tailings at effective voltages of 100 and 500 kPa. The similarity in the water retention behavior of GeoWaste and pure tailings was dependent on the proportion of the mixture, in which mixtures with larger tailings fractions exhibited water retention in the soil more comparable to pure tailings.

Other mixtures with residues have been tried with residues from thermal processes, such as fly ash. Previous studies on the use of fly ash as a binding agent to improve the geotechnical properties of mine tailings are limited, despite the potential application. The horizons of waste valorization are opened, mixing them. (Fall et al., 2009) investigated the feasibility of using bentonite paste waste (BPW) as a barrier material (basal and cover) for mine waste containment facilities. Values as low as 1 x 10^{-9} and 4 x 10^{-9} cm/s are obtained in 8% and 4% of bentonite and RPB, respectively. In addition, when compared to the conventional compacted clay-bentonite or sand-bentonite barrier with 12% bentonite concentration, it appears that the 4% RPB has a 66% reduced cost.

2.2.3 Red mud

The red mud residue (RM), composed of solid and metallic oxides, is one of the industrial by-products generated by the aluminum industry, a residue resulting from the refining of bauxite (D. Rubinos et al., 2015). About 0.8-2.5 tones of RM waste are generated per ton of alumina production. Globally, it is estimated that more than 120 million tons of RM waste are generated each year (Gangadhara Reddy & Hanumantha Rao, 2016; Pandian, 2004). The compaction characteristic is improved in terms of low ideal moisture content and resistance to compression after marginally increased biotreatment. The value of the unconfined compressive strength (UCS) of the biotreated red sludge increased to 298.6kPa compared to 136.5kPa for the untreated red sludge (Pandian, 2004).

(D. Rubinos et al., 2015) tested an extended permeation experiment (90 days) on two samples of RM, which were compacted under ideal conditions (w_{opt} = 29.2 ± 0.2%; ρ_d = 1.58 ± 0.04 mg/m^3), the hydraulic conductivity of both samples remained essentially constant at K = (2.1 ± 1.5) x 10^{-7} cm/s throughout the permeation period. Therefore, it is concluded that the RM can be compacted to obtain low enough hydraulic conductivity using a moderate compaction effort (standard proctor)

2.3 Biomass wastes

2.3.1 Paper mill sludge

Waste from wastewater treatment plants in paper mills, called paper mill sludge, have been used to build hydraulic barrier layers in landfill covers, in addition, paper mill sludges are mixed with sand and soil clayey to form topsoil (Kraus et al., 1997). Cellulose and paper sludge consist mainly of fibers, fillers, clays and several other minor impurities that can have low hydraulic conductivity when properly compacted. The geotechnical characteristics of the sludge in the paper mill are very different from typical clays, but in general they behave in a similar way (Kraus et al., 1997). These properties can vary when dealing with different paper-producing plants.

According to overload studies (Kuokkanen et al., 2008) the hydraulic conductivity of sludge from a paper mill originating from a paper mill in northern Finland at a pressure of 30kPa was 4.4 x 10^{-8} cm/s and 1.7 x 10^{-8} cm/s at a pressure of 100kPa. These values meet well the values generally required between 1.0 x 10^{-7} cm/s and 1.0 x 10^{-9} cm/s for a geological barrier at the base of the landfill and on the sides of landfills in the European Union. Geotechnical properties of the paper sludge produced at Erving Paper Mill in Erving, Massachusetts, USA, concluding that, despite the high water and organic content, low shear forces and a high degree of compressibility However, the construction sequence of the paper sludge lid plays an important role in the stability of the final lid.

2.3.1 Agriculture ashes

Agroindustrial waste has received attention due to its combustion because of its pozzolanic properties and can replace fine-grained clays and soils in the construction of landfill linings. Bagasse ash (BGA), rice husk ash (RHA) and palm oil fuel ash (POFA) are prominent examples of such residues (D. A. Rubinos & Spagnoli, 2018).

Laboratory tests were carried out (Osinubi & Eberemu, 2010) on residual compacted granite soil treated with 0 to 15% palm oil ash (POFA) to assess its hydraulic conductivity for use in landfills and resulted in an improvement in soil plasticity, while $p_{d,max}$ and moisture decreased and increased, respectively, with the POFA content. In general, k decreased to a 10% POFA content, for which k was as low as 2.3×10^{-9} cm/s at w_{opt} = 19% when using the modified Proctor effort; but increased to $K > 10^{-7}$ cm/s unsuitable for higher POFA. Also, tests were conducted on a reddish-brown lateritic soil treated with up to 12% bagasse ash to assess its suitability in applications of waste containment barriers and properties such as plasticity index, hydraulic conductivity, volumetric shrinkage and unconfined compressive strength tests (UCS) were performed. In the 4-12% range of bagasse ash, all samples compacted in standard Proctor efforts recorded hydraulic conductivity values below 1×10^{-9} m/s, which makes it suitable for use in barrier applications of waste containment.

2.4 Thermal processes wastes

The total or partial combustion of materials generates waste, a process that is classified as a thermal process, the tailings are usually found in the form of ash, be it fly or inert, slag or sand. Due to a granulometry like that of clays and sands, natural usually used in civil construction, the capacity of each tailings was analyzed according to the relevant retention earth works.

2.4.1 Coal combustion ashes

In general, about 70% of the solid waste derived from coal combustion is fly ash, the portion of ash small enough, in terms of particle size, to be dragged into the flue gas and carried away from the combustion site. Due to its small size, an alternative to the conventional disposal of coal washing waste is the disposal of coarse tailings and tailings. The New Hope Colliery mixtures with the two components in different proportions were tested, the drained force does not seem to be very sensitive to the mixture due to its compressibility, but the permeability depends a lot on the proportion of tailings in the mixture (Mohan et al., 1997) collaborates for the use of coal ash in geotechnical applications.

Charcoal fly ash is a pozzolanic material and was divided into two classes, F and C. Class F fly ash is produced from the burning of anthracite and bituminous coal. Class C fly ash is produced from lignite and sub-bituminous coal and can contain significant amounts of calcium hydroxide and, as a result, can be self-cementing.

Several studies have been carried out to investigate the use of fly ash as in hydraulic barrier constructions (Palmer et al., 2000); the hydraulic conductivity was tested from Harrison and Amos's stabilized fly ash from West Virginia, USA, acchieving 7.2×10^{-6} and 5.0×10^{-5} cm/s, respectively, when compacted in the best water content. Increasing the amount of lime or cement has decreased hydraulic conductivity. Hydraulic conductivities of less than 10^{-7} cm/s are not easily achieved in the laboratory. Various amounts of Class C sand and fly ash have been added to reduce hydraulic conductivity. The addition of Class C fly ash to 30% reduced hydraulic conductivity to near, but not below 10^{-7} cm/s, if the compaction water content was greater than the ideal water content. The design mixture and the mixture used after all include a mixture of Class C fly ash (38%) and equal parts (31% each) of lower ash as a substitute for sand and Class F fly ash. Laboratory tests on these mixtures showed that hydraulic conductivities close to or less than 10^{-7} cm/s could be obtained for the optimum wet compaction water content.

2.4.2 Foundry sands

Foundries use sand in two ways: for molds that form the external part of the foundry and in cores that form the internal shapes and cavities of the foundry. The excess of foundry sands from metal foundry plants generally contains a significant amount of bentonite (up to 15%) and, therefore, can have low hydraulic conductivity, also shows low sensitivity to moisture and compaction effort and environmental impact. These attributes make some foundry sands excellent hydraulic barrier materials (Abichou et al., 1998). A high-bentonite foundry sand is green sand, a mixture of uniformly classified fine silica sand, bentonite and organic binders that are used to make foundry molds in gray iron foundries.

(Abichou et al., 1998) tested residual green sand from the foundry in central Wisconsin as a hydraulic barrier material, resulting in hydraulic conductivities ranging from 2.3×10^{-9} to 2.5×10^{-8} cm/s, results consistent with the behavior of sand-bentonite reported by (Kraus et al., 1997) which are accepted as hydraulic barrier material in Wisconsin (less than 10^{-7} cm/s). Liquid limits were > 20%, plasticity index from 0 to 7% and bentonite content > 6% were also recommended for the use of foundry sands in the construction of hydraulic barrier. In addition, (Kumar et al., 2019) found that the foundry sands exhibited a 37° shear strength angle, another parameter used for barrier materials.

2.4.2 Blast furnace slag

Blast furnace slag (BFS) is a product of iron production, which has been widely investigated and used, particularly as a supplementary cementitious material for cement or alkali-activated material, due to its high hydraulic property or alkali activation reactivity. Typically, 200 to 400kg of liquid slag are generated for each ton of hot metal produced. The generation of steel slag in the world is estimated to be between 170 and 250MT in 2015.

Based on the properties of the index in laboratory tests, steel slag from the blast furnace (BF) can be considered a construction landfill alternative. The compaction behavior of the material is like granular soils. The BF steel slag exhibited a shear strength angle of 37º, respectively. A comparative study of the properties of foundry sand and BF steel slag is carried out with the conventional filling material, and the two residues considered in the study are evaluated for filling applications (Kumar et al., 2019). (Sivapullaiah & Baig, 2011) tested mixtures in different proportions of fly ash and ground granulated blast furnace (GGBF). Fly ash and GGBF, considered waste, are promising as building materials. Traditionally used in concrete individually. Compression tests have shown that the unconfined compressive strength (UCS) of the fly ash/GGBF mixture increases nominally with increasing GGBF content. Mixtures with GGBF content of 30 and 40% show greater resistance compared to individual materials. However, the rate of strength gain is very slow, due to low alkalinity and/or enough calcium ions. The mixtures have yet to be tested for hydraulic conductivity, as well as individual material.

2.5 Water treatment sludge

A more sustainable destination for water treatment sludge (WTS) is its use in earthworks and as landfill lining. However, due to its high-water content and plasticity, the investigation of WTS's workability in construction procedures is mandatory. (Tsugawa et al., 2017) observed its thixotropy in Cubatão WTS, São Paulo, Brazil, as well as (Wong et al., 2016) of three different WTPs in the USA. In geotechnical engineering, thixotropy is the increase in resistance over time (when the system is left at rest), with a constant void proportion and constant water content, after remodeling, that is, when the system is sheared and the resistance decreases.

Lime sludge is a waste material from the water treatment plant. Tests were conducted with a comprehensive investigation into the use of lime sludge in unconfined compressive strength (UCS) and the retraction behavior of commercially available kaolinite clay, samples were added to kaolinite (EPK clay) by the dry weight of the EPK clay. The results show that, with the increase in the lime sludge content, the UCS value increased initially, followed by a slight decrease. An increase in the curing period resulted in an increase in the resistance to unconfined compression. In addition, an increase in the lime sludge content led to a reduction in the shrinkage potential.

Research on the hydraulic conductivity of water treatment sludge is lacking, however, it has the potential to be used as a covering material in landfills, but it can also be studied as a bottom material if it presents low hydraulic conductivity (< 10^{-7} cm/s).

3. RESULTS AND DISCUSSIONS

In the following paragraphs, the main conclusions are summarized in table 1, research limitations and recommendations for future studies are discussed. According to overload studies, hydraulic conductivity is a potential feature of many materials, such as waste and residues, which should be further explored by researchers and not only as individual materials, but as mixtures that can obtain better performance, solving part of the problems explained in this article, such as excess waste in landfills, the future lack of raw materials, such as clays, high costs and generation of geosynthetic waste. Each of the reviewed residues has potential uses as hydraulic barriers, according to their physical, chemical and mineralogical characteristics and due to the results of laboratory and field tests.

Table 1. Overall wastes literature and future investigations possible.

Industrial Waste	Advantages	Disadvantages	Utilization	Future Researches
Drilling mud	Low cost Good compost incorporation Shear strength	Contaminants presence High k	Slope stability Landfill cover	Chemical compatibility Long-term behavior Risk of contaminants
Mining tailings	Low cost Good compaction Low k	Need mixtures with bentonite or other clay	Dams basal and cover	Long-term behaavior
Red mud	Mechanical resistance Chemical resistance	High k	Landfill cover	Long-term behavior
Paper mill sludge	Low cost Low k Field mechanical resistance	Low shear strength	Landfill cover	Chemical compatibility
POFA	Plasticidy index Low k	Need mixtures with bentonite or other clay	Soil additive	Mechanical properties Chemical compatibility
Bagasse ash	Shear strength Chemical compatibility	Disponibility Need mixtures with bentonite or other clay	Soil additive	Durability Long-term behavior
Coal ashes	Shear strength Heavy metal sorption	Need mixtures with bentonite or other clays or additives Compaction	Landfill cover Soil additive	Long-term behavior Chemical compatibility Mixtures
Foundry sand	Mechanical resistance Field performance	Low strength Need mixtures with bentonite or other clay	Liners	Chemical compatibility
Blast furnace slag	Compaction Shear strength Field performance	Wet-dry cycles	Landfill cover Soil additives	Chemical compatibility Long-term behavior
WTS	Low k	Need dehydration Contaminants presence	Landfill cover	Mixtures Chemical compatibility Long-term behavior

4. CONCLUSIONS

Mine waste, due to its low hydraulic conductivity and good compactness, has the potential to be used in basal or waste containment coverings. Although they need alterations, such as rock waste or bentonite (Fall et al., 2009) and the presence of metals. Long-term behavior and chemical compatibility with different tailings remain to be investigated. Red mud, despite its oxidative compositions, has the potential to be used in reactive coatings of industrial and mining waste, due to low hydraulic conductivity and mechanical resistance. Like tailings mining, it needs to be investigated in long-term behavior (D. Rubinos et al., 2015).

Sludge from paper mills has been studied in many countries, from the USA (Kraus et al., 1997) to Finland (Kuokkanen et al., 2008). Because of the proper hydraulic conductivity and mechanical performance, it can be used in landfill covers. But it needs more studies on its biodegradation, long-term performance and slope instability. Agroindustrial ashes are a new focus of attention for clay substitutes in the landfill, studies are still beginning to discover their physical and chemical properties, the most studied are bagasse ash, rice husk ash and palm oil fuel ash, but there is a lack of research using these materials individually, or even mixing and testing biodegradation, long-term performance and mixtures of proportion.

The coal fly ash, or bottom ash, has the potential to be used as a composition of coatings and coverings in landfills, due to low hydraulic conductivity and high compaction rate. But it needs amendments and has the presence of metal, also needing research on chemical compatibility and installation on a field scale. Foundry sand, such as green sands (Abichou et al., 1998) and blast furnace steel slag (Kumar et al., 2019; Sharma & Reddy, 2004) need further studies on the leaching risks of metals but can be applied in hydraulic barriers due to its low plasticity index and typical behavior of clays with low hydraulic conductivity and high resistance to unconfined compression.

Low hydraulic conductivity plays an important role in the applicability of water treatment sludge to landfill roofs (Raheem et al., 2018; Tsugawa et al., 2017). But, due to the lack of research, he needs in the field of applied changes, mechanical stability and long-term behavior. In addition to varying greatly according to the region and the source of the water to be treated.

These studies on a part of industrial by-products showed a high potential for use in hydraulic barriers in earthworks, seeking a decrease in the excess of landfill waste and lower cost alternatives for retaining solid waste materials and wastewater.

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