Mineralogical Selection of Rocks for Internal Drainage in Tailings Structures

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ABSTRACT

Internal drainage systems are essential elements for hydraulic control and geotechnical safety in tailings structures, as they contribute to pore-pressure dissipation, phreatic surface drawdown, and the maintenance of hydraulic gradients compatible with embankment stability. The performance of these systems depends not only on the gradation and permeability of the granular material, but also on the physical durability, mineralogical stability, and geochemical behavior of the rock used as drainage aggregate. This paper presents a technical review of criteria applicable to the selection of rocks for internal drainage systems, with emphasis on the properties that control the performance of filters and drains in tailings structures. The review considers hydraulic compatibility and internal stability, physical-mechanical durability, degradation resistance, and potential geochemical alteration, based on international references for filter, dam, and tailings design, as well as standards for the characterization of aggregates and rocks. The results indicate that sound, compact, slightly weathered silicate rocks with low fines generation, such as slightly foliated quartzites, granites, sound gneisses, basalts, and diabases, tend to perform better as drainage materials. Conversely, friable, highly foliated, micaceous, argillized, sulfide-bearing, or carbonate rocks require specific investigation because they may undergo fragmentation, dissolution, secondary precipitation, and physical or chemical clogging of voids. The review consolidates screening parameters including Los Angeles abrasion, water absorption, fines content, particle shape, slake durability index, clay mineral content, total sulfur content, NP/AP ratio, and degree of weathering.

1. INTRODUCTION

Internal drainage systems are critical hydraulic-control elements in tailings structures because they convey seepage flows, reduce pore pressures, and contribute to embankment stability. The filter literature establishes that their effectiveness depends on adequate retention of the protected material, drain permeability, and internal stability of the granular medium, as discussed by Sherard et al. (1984), Kenney and Lau (1985), Federal Emergency Management Agency [FEMA] (2011), and Fell et al. (2015).

However, in long-life structures, the initial particle-size distribution alone is not sufficient to represent the drainage material performance. Fragmentation during quarrying, crushing, hauling, placement, or operation may increase fines generation, while mineralogical alteration, dissolution, and chemical precipitation may reduce permeability. Goldich (1938) shows that mineral stability controls weathering susceptibility; Mitchell and Soga (2005) describe the behavior of clay minerals; and

Singer and Stumm (1970) and Blowes et al. (2003) demonstrate the relevance of sulfide oxidation to acidity generation and precipitate formation.

In mining regions such as the Quadrilátero Ferrífero, selection is complicated by the variability of quartzites, itabirites, phyllites, schists, dolomites, gneisses, and ferruginous rocks. Alkmim and Marshak (1998) describe the regional geological complexity, which is reflected in differences in foliation, weathering, mica content, and the occurrence of carbonates and sulfides. Therefore, this paper aims to consolidate technical criteria for the mineralogical selection of rocks intended for internal drainage in tailings structures by integrating geological, geotechnical, and geochemical aspects.

2. METHODOLOGY

The methodology consisted of a technical review focused on the evaluation of rocks for use as coarse aggregate in internal drains. Four groups of criteria were considered: petrographic and mineralogical characterization; physical-mechanical performance; physical-chemical durability; and geochemical stability. This framework relates geologic properties to the expected material behavior during processing, construction, and operation.

Petrographic characterization was treated as the initial screening step. ABNT NBR 7389-2 (2009) and ASTM C295/C295M (2019) provide guidance for identifying sulfides, reactive carbonates, micas, clay minerals, microcracks, foliation, and degrees of weathering. The physical-mechanical assessment included gradation, fine materials, particle shape, absorption, Los Angeles abrasion, and slake durability, based on ABNT NBR 7219 (2019b), ABNT NBR 7809 (2019a), ABNT NBR 16917 (2021), ABNT NBR 16974 (2022), ASTM C88/C88M (2018b), and ASTM D4644 (2016).

The geochemical assessment was directed at materials containing sulfides, carbonates, or weathering features. Total sulfur content, the NP/AP ratio, and acid-generation potential were considered according to Mine Environment Neutral Drainage Program [MEND] (2004), Price (2009), and ASTM D5744 (2018a). The consolidated limits were interpreted as screening criteria and not as substitutes for project-specific studies.

3. RESULTS AND DISCUSSION

3.1 Mineralogical and Geochemical Influence

Mineralogical composition controls the durability and hydraulic efficiency of internal drains. Sound, compact, slightly foliated silicate rocks, such as quartzites, granites, sound gneisses, basalts, and diabases, tend to perform better because they combine mechanical strength, low porosity, limited alteration, and lower fines generation, consistent with Fell et al. (2015) and Wyllie and Mah (2004).

Rocks containing expansive clay minerals, argillized matrix, abundant micas, intense foliation, or high degrees of weathering show greater tendency toward disaggregation and fines production. Mitchell and Soga (2005) associate clay minerals with swelling and loss of particle stability, while Fell et al. (2015) recommend limiting clay minerals in filter materials. Phyllites, schists, and friable itabirites require caution because anisotropy and platy fabric may favor fragmentation under wetting-drying cycles.

Sulfide minerals represent a relevant geochemical risk in permanent systems. Pyrite and pyrrhotite oxidation may generate acidity, mobilize metals, and promote the precipitation of hydroxides, sulfates, and salts within drain voids, reducing permeability, as described by Singer and Stumm (1970) and Blowes et al. (2003). Price (2009) recommends, as a screening criterion, total sulfur content below 0.3% and an NP/AP ratio (Neutralization Potential/Acid Potential) greater than 2.0. Carbonate materials may neutralize acidity but may also be subject to dissolution and secondary precipitation; therefore, they should be evaluated together with the hydrogeochemical context

3.2 Physical-Mechanical Performance of Materials

The review enabled the consolidation of screening parameters for permanent drainage materials, as presented in Table 3.1. These values do not replace filter gradation design or compatibility checks with the protected material, but they provide reference limits to reduce the risk of degradation, fines generation, clogging, and loss of hydraulic performance. Final selection should simultaneously consider retention and permeability criteria, according to U.S. Bureau of Reclamation [USBR] (2011), FEMA (2011), U.S. Army Corps of Engineers [USACE] (1993), Sherard et al. (1984), and Kenney and Lau (1985), as well as aggregate quality and durability criteria according to applicable ABNT and ASTM standards.

Table 3.1 Recommended parameters for drainage materials in tailings structures.

Parameter	Recommended Range	Technical Reference
Los Angeles abrasion	< 35%	ABNT NBR 16974; ASTM C131/C535
Water absorption	< 2%	ABNT NBR 16917
Fine materials	< 1%	ABNT NBR 7219
Platy-shape index	< 15%	ABNT NBR 7809
Slake durability index (Id_2)	> 85%	ASTM D4644
Soundness loss	< 10%	ASTM C88/C88M
Clay minerals	< 5% (prefer. < 2%)	Fell et al. (2015)
Total sulfur (S_{tot})	< 0.3%	Price (2009)
NP/AP ratio	> 2.0	MEND (2004); Price (2009)
Degree of weathering	W1 to W2	ISRM (1981)

Source: Compiled by the authors from the references listed in the table. ISRM = International Society for Rock Mechanics.

Materials with high Los Angeles abrasion tend to be more susceptible to fragmentation during crushing, hauling, placement, and operation, according to the wear-assessment procedures established by ABNT NBR 16974 (2022), ASTM C131/C131M (2020), and ASTM C535 (2020). For permanent drains, values below 35% are recommended as a screening criterion, whereas values above 40% should be interpreted as indicating an increased risk of fines generation and permeability degradation.

Water absorption is also relevant because high values indicate greater accessible porosity, larger reactive surface area, and greater susceptibility to physical-chemical alteration. It may be determined according to ABNT NBR 16917 (2021) or ASTM C127 (2023), adopting absorption below 2% as a reference for permanent drainage aggregates. In addition, the content of fine materials, according to ABNT NBR 7219 (2019b), and

particle shape, according to ABNT NBR 7809 (2019a), should be controlled to avoid excessive fine and platy particles, which may reduce permeability and favor internal instability of the granular medium.

3.3 Applicability in the Quadrilátero Ferrífero

The application of the selection criteria in the Quadrilátero Ferrífero must consider the strong geological heterogeneity of the region, which comprises Archean granitoid-gneiss complexes, greenstone belts, and metasedimentary sequences of the Minas Supergroup, resulting in significant variability in rock quality and weathering degree (Alkmim & Marshak, 1998; Endo et al., 2019).

Within this context, granitoid-gneissic complexes occurring in areas such as Mariana, Sabará, Santa Luzia, Contagem, Ribeirão das Neves, and Rio Manso represent potential sources of aggregates for internal drainage systems. These lithologies are mainly composed of granites, granitoids, gneisses, and migmatites, and are commonly associated with good mechanical strength, low porosity, and high durability. When properly crushed and quality controlled, they may provide suitable drainage aggregates with adequate particle-size stability and low fines generation, supporting long-term hydraulic performance.

From a logistical perspective, the proximity of these sources to mining operations may reduce transportation distances and supply costs. However, material selection should not rely solely on regional occurrence, requiring instead individual assessment of each source through representative petrographic, physical-mechanical, hydraulic, and geochemical characterization prior to use.

4. CONCLUSION

The review showed that gradation and hydraulic criteria are necessary but not sufficient to ensure the performance of internal drainage systems in tailings structures. Long-term functionality also depends on the physical durability, mineralogical stability, and geochemical behavior of the rock used as drainage aggregate. Classic filter references, such as Sherard et al. (1984), Kenney and Lau (1985), USBR (2011), FEMA (2011), and USACE (1993), should be integrated with petrographic, durability, and geochemical characterization criteria to support material selection.

Sound, compact, slightly weathered silicate rocks with low fines generation, such as slightly foliated quartzites, granites, sound gneisses, basalts, and diabases, tend to be more suitable for permanent drains, provided that they meet gradation and hydraulic-compatibility requirements. Friable, weathered, foliated, micaceous, argillized, sulfide-bearing, or carbonate materials require specific investigation because they may favor fragmentation, disaggregation, chemical alteration, secondary precipitation, and clogging of drain voids.

The application of these recommended criteria in Table 3.1 must always be accompanied by an analysis of the filter design, a characterization of the quarry or source of backfill material, and quality control during construction, in order to ensure the hydraulic stability and long-term safety of the waste structures.

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