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Effect of underliner on geomembrane strains in heap leach applications☆

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ABSTRACT

A review of 92 heap leach projects from 15 countries provides a starting point for a series of experiments, at 22 °C and a vertical pressure of 2000 kPa, to examine short-term puncturing and the development of geomembrane strains that could affect longer-term performance. Underliners of gravel with some sand or those of gravel and sand caused significant puncturing and excessive strains in the geomembrane for the conditions examined. The shape of the underliner grading curve had a much greater effect on the potential for puncturing and the magnitude of the strains in the geomembrane than just the maximum particle size. Of the six granular underliners examined, the best performance was for the well graded gravelly sand with some silt which offered sufficient support to minimize the strains in the geomembrane due to the overliner while not inducing significant strains directly from the underliner. Nevertheless even in this case the maximum strain of 11% is almost double the maximum recommended in the literature for ensuring good long-term performance of the geomembrane. Consideration of composite liners with GCLs and compacted clay liners shows that the more deformable the foundation, the larger are the indentations and strains induced in the geomembrane by a given overliner. For the specific conditions examined, it is shown that there was no apparent improvement in performance for an LLDPE geomembrane versus the HDPE geomembrane tested. A 540 g/m^2 geotextile protection layer above the geomembrane was also found to be insufficient to prevent significant strains in the geomembrane due to the overliner examined.

1. Introduction

Heap leaching has gained wide acceptance as a relatively low cost method for the recovery of metals (Smith, 2004). The mined ore is crushed and placed in 5–10 m thick lifts over a geomembrane lined pad (Breitenbach, 2005). A chemical solution, with the characteristics appropriate to leaching the mineral to be extracted, is applied at a controlled rate to the ore, most commonly via a drip irrigation system. As the solution percolates through the ore it dissolves the metal of interest, producing a solution referred to as the 'pregnant liquor' or 'pregnant leach solution' (PLS). This solution is collected at the base of the heap leach pad and directed to a recovery plant for metal recovery (Fourie et al., 2010).

The geomembrane liner serves to minimize the loss of the PLS (and hence valuable minerals as well as the process reagents) but also minimizes environmental impact due to the escape of PLS. Geomembranes provide an excellent barrier to the PLS except where there are holes (Rowe, 2012). Thus it is desirable to minimize the number of holes throughout the period when the PLS will be captured for mineral recovery and potentially for a longer period during which the escape of fluids leached from the ore could have a negative impact on the environment.

Heap leach pads represent a challenging environment for any liner. The challenges include high stresses with ore heights reaching 240 m, and stresses of up to 4000 kPa on the liner, having been reported (Lupo, 2010). Additional factors that could affect liner performance include the presence of a coarse overliner, gravel in the underliner, very high or low pH leach solution (Abdelaal et al.,

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2011, 2012), hydraulic heads of up to 60 m, and potentially high temperatures (e.g., Thiel and Smith, 2004). Lupo and Morrison (2007) developed general guidelines for geomembrane selection based on the applied load, characteristics of the foundation, overliner materials, and liner bedding materials. However, specific testing should be conducted to assess geomembrane liner performance for the given site conditions.

The cylinder test method (as described in Environmental Agency, 2006; Shercliff, 1998; Brachman et al. 2000; Thiel and Smith, 2004; Lupo and Morrison, 2007) is one technique used to assess the potential for geomembrane puncture for a given underliner and overliner. In these high-load static puncture tests, the proposed underliner and overliner materials are placed below and above the geomembrane of interest and subjected to applied pressures up to 2000 kPa (Thiel and Smith, 2004). These tests focus on puncture due to vertical load. They do not represent lateral or horizontal loading that may be induced due to stacking equipment, angle of repose face angles of the first ore lift, or the relatively steep liner grades present on some pads. Because of the horizontal loading (and strain) one may also examine the condition of liner samples coming out of a large direct shear test as representing a limiting condition for horizontal loading. Both the cylinder and the direct shear tests provide information about potential short-term puncture at the temperature at which the test is performed. While it is certainly necessary to avoid short-term puncture, the absence of puncture does not mean that holes will not develop with time in areas where there are high tensile strains (Seeger and Muller, 2003; Peggs et al., 2005). Yet there is a paucity of archival literature dealing with strains in geomembranes used in heap leach applications.

The objectives of this paper are to: (a) identify common features of heap leach pads, (b) examine the effect of the underliner on puncture and short-term tensile strains induced in 1.5 mm thick HDPE geomembrane, and (c) examine the relative performance of 1.5 mm thick HDPE and LLDPE geomembranes under similar conditions.

2. Characteristics of heap leach pads

The unit weight of the ore in a heap leach pad depends on a number of factors with typical moist values reported to range from 17.3 kN/m^3 (110 pcf) to 20.4 kN/m^3 (130 pcf) with the maximum unit weight occurring during leaching (Breitenbach and Thiel, 2005). The present study included a review of 92 heap leach projects from 15 countries (Argentina, Brazil, Chile, Colombia, Ghana, Indonesia, Mexico, Namibia, Niger, Peru, Philippines, Poland, Turkey, USA, and Uzbekistan) to identify common features. Data were available regarding the height of ore at 72 of the projects examined (Fig. 1). Approximately 51% of cases had ore heights of 50 m or less (i.e.,

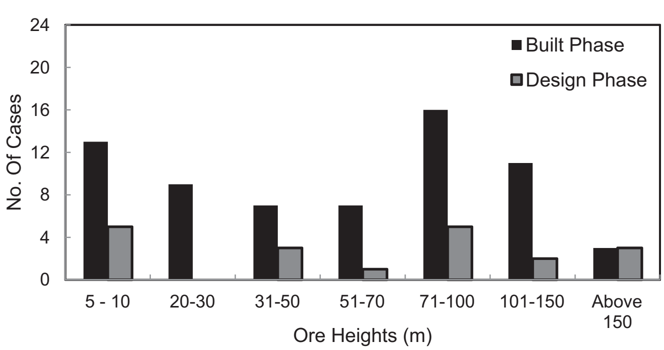

Fig. 1. Histogram of heap leach ore height for 72 cases where data was available.

typically less than about 1000 kPa of vertical pressure), 90% were 100 m or less (≤2000 kPa), but 10% were 150 m or higher (≥2600 kPa) with a maximum height of 238 m (≤4800 kPa). Based on this information, the experiments conducted in this study were for a pressure of 2000 kPa (i.e., covering 92% of the cases).

2.1. Underliner material

Lupo and Morrison (2007) indicated that, where possible, a native soil is used as the underliner to minimize construction costs. They indicated that typically requirements for the underliner include a non-gap graded particle distribution, a maximum particle size of 38 mm, greater than 15% fines (i.e. <0.075 mm), a plasticity index greater than 15%, and a saturated hydraulic conductivity of less than 1×10^{-8} m/s. Lupo and Morrison (2007) presented a grain size envelope of underliner materials from several mining projects as defined by the curves UL2 and UL6 in Fig. 2. Of the 92 cases reviewed as part of the current study, the underliner was described as clay in 48% of cases (although clay should probably be interpreted as soil with significant fines and these fines may not actually include significant clay in some cases), native soil in 9%, a GCL in 5%, tailings in 4%, silt/sand in 3%, and was not given in 30% of cases.

2.2. Geomembrane

The literature indicates that the most common geomembrane used for a leach pad liner is 1.5 mm polyethylene (either HDPE and LLDPE) but that thicker PE is used occasionally for deeper heaps and 0.75–1.0 mm PVC has been occasionally used (Thiel and Smith, 2004; Lupo, 2008). Data on the liner were available for 88 of the 92 cases examined in this study. This data indicated that HDPE was used in 75% of cases (presumably because of its good chemical resistance), LLDPE in 22% of cases, and PVC in only 3% of cases. Although LLDPE only represented 22% of cases examined in total, there appeared to be a trend of increasing popularity of LLDPE in the more recent cases and for heap pads in the design phases LLDPE was being considered in about 50% of cases.

The thickness of geomembrane used was 1 mm in only 5% of cases, with PVC being used for heaps less than 20 m and HDPE for heaps less than 50 m. A thickness of 1.5 mm was used in 46% of cases (40% HDPE, 6% LLDPE) with a maximum heap height of 120 m for HDPE and 90 m for LLDPE. A thickness of 2 mm was used in 45% of cases (31% HDPE, 14% LLDPE) with the HDPE being used for heap heights up to 238 m and LLDPE up to 160 m. The 2.5 mm

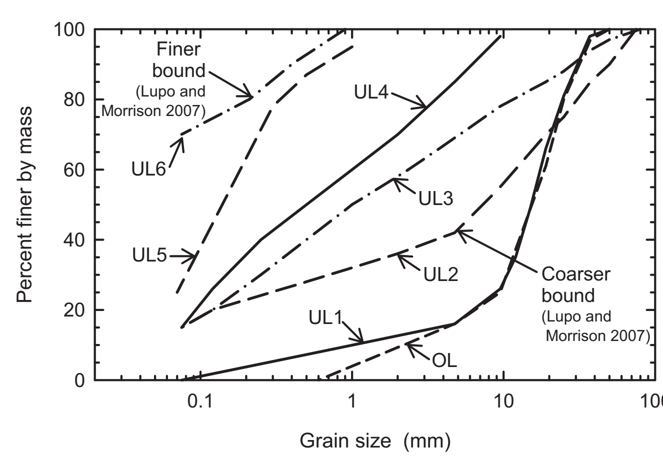

Fig. 2. Grain size distribution of underliners (UL1–UL6) and overliner examined (OL) in this study and bounds of underliner in projects reported by Lupo and Morrison (2007).