Improving Till by Adding Green Liquor Dregs in Sealing Layers to Control AMD – A Pilot Study

Maria Mäkitalo[1], Josef Mácsik[2], Christian Maurice[1,3] and Björn Öhlander[1]

1. *Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Sweden*
2. *EcoloopAB, Sweden*
3. *Ramböll Sverige AB, Sweden*

ABSTRACT

A common solution to minimize the formation of acid mine drainage (AMD) in sulphide-bearing mine waste is to use a conventional cover. The cover is usually constructed by using natural soils, in the boreal zone often till. Shortage of fine-grained till close to mines suitable as sealant material is often an issue. In the last years, considerable research has been carried out to use residual products from other industries in the control of AMD. Green liquor dregs (GLD), an alkaline and inorganic residual product generated by the sulphate pulp and paper mills, has shown desirable properties such as low hydraulic conductivity, high water retention capacity as well as long term sustainability, to be a candidate for constructing sealing layers in cover system designs. However, the geotechnical strength of the material is insufficient for engineering applications. If this issue can be overcome, developing a cover system with GLD would be possible. The challenge remains of finding a solution that is viable in regards to logistics and transport economics. To reduce transportation costs but take advantage of the physical properties of the residual product, GLD was blended with two types of till in a pilot scale study with the aim to optimize the use of GLD in a sealing layer application. 5-15% (wet weight) GLD was found sufficient to take full advantage of the physical properties of the residual product and to minimize transportation costs. Different mixing techniques were also evaluated. The results show that the quality of the till in regards to hydraulic conductivity and water holding capacity could be improved with the addition of only 5% GLD. A short and efficient mixing was preferred since mixing the material too vigorously released the bounded water resulting in increased water content and a reduction of the compaction efficiency. It results in a material that is difficult to apply and use in sealing layer constructions. Transportation, mixing and application costs are comparable or lower than of fine-grained till.

Keywords: Acid mine drainage, Sealing layer, Dry cover, Green liquor dregs

INTRODUCTION

Mining generates mainly two types of residues: waste rock and tailings. Waste rock is the material that lacks economic amounts of mineral and is removed to access the ore, while tailings are finely ground material that has been processed in the mill. Mine waste from sulfide ores has the potential for a significant environmental impact because it often contains iron sulfides such as pyrite and pyrrhotite. Acidification caused by oxidation of these minerals occurs when they are exposed to atmospheric oxygen (Höglund et al. 2004). If no alkaline material is present to consume this acidity, water entering the waste transports the oxidation products. This leachate is called acid rock drainage (ARD) and often contains high levels of heavy metals. ARD is one of the most significant challenges when dealing with sulfidic, pyrite rich mine waste. One common technique to mitigate the formation of ARD is to apply a barrier made of soil (in Sweden often till) on top of the mine waste that has a high degree of water saturation to limit oxygen diffusion and a low hydraulic conductivity to reduce water percolation. A protective layer is placed on top of the barrier to protect its integrity. Using till in barriers, or so-called sealing layers, is often associated with large costs due to the long distances that the material has to be transported**,** as finding till of suitable quality that can function in sealing layers and is located close to the mine is seldom possible. If the costs can be kept low, modifying the till available at the mining area may, therefore, be an alternative. To achieve a till that complies with the qualifications of a sealing layer (a highly saturated layer with a low hydraulic conductivity $<10^{-8}$m/s) to reduce oxygen ingress. One way to reduce the heterogeneity and increase the sealing properties of the till is to adjust the particle size distribution and change the porosity. It can be done by removing bigger rocks and adding a fine-grained material of suitable quality.

One potential candidate is the non-hazardous industrial residual waste Green liquor dregs (GLD) that has been characterized previously (Mäkitalo et al. 2014). GLD is the largest waste fraction retrieved in the chemical recovery cycle at sulfate pulp and paper mills and the production in Sweden is ~240 000 t per year. The material has small particle size (clay-silt fraction) and high porosity (>75%). In addition, it showed favorable qualities such as low hydraulic conductivity and high water retention capacity for use in sealing layers to reduce oxygen ingress in the prevention of AMD (Mäkitalo et al. 2014). However, GLD has low shear strength (Mäkitalo et al. 2014) making it difficult to use in engineering applications. It would also be expensive to transport GLD due to the large quantities needed per m^2 and its high water content. However, adding GLD to modify and improve the till to a grade where it can be used as a sealing layer could be an economically viable solution.

Mixing large volumes of **material** poses the risk of inadequate **mixing, therefore,** the mixing of selected proportions of till/GLD was conducted under both laboratory and field conditions. In the field, two different techniques, a loader with a crushing bucket and a mobile asphalt plant, were used in the frame of a pilot scale experiment. The aim was to find a mix that had decreased hydraulic conductivity and increased water retention capacity compared to till to decrease the oxygen influx through the material. The ability to be compacted under field conditions was also an important criterion.

METHODOLOGY

Material

GLD was obtained from the Smurfit Kappa sulphate pulp and paper mill in northern Sweden. Till was excavated at the Ragn-Sells waste management site at Brännkläppen, Sweden, referred to as Till A herein. The till was screened for a particle size of <20mm and had a content of 30% of particles <0,063mm. Another till, from BDX Material, Sweden, with the same maximum particle size, but with the content of <10% of particles <0,063mm was obtained and used to compare the tills. The till is referred to as Till B.

Method

Compaction properties such as maximum dry density, porosity and the optimum water content of till/GLD mixes blended in the laboratory with the proportions 90/10, 80/20, 70/30 and 50/50 were carried out by an accredited laboratory (MRM, Luleå, Sweden) with a standard procedure (EN 13286-2, 2010). Eight mixes of Till A or Till B blended with 5-15% GLD using either a Loader with a crushing bucket (Allu Group Inc.) (Figure 1) or a Mobile Asphalt Plant (Figure 2) were prepared. Total volumes of 10-60 tons were mixed to evaluate the ability to obtain a homogenous product and the production efficiency. The composition of the different mixes and the total amount mixed are shown in Table 1. The production speed of the machineries was recorded to get an estimation of the production costs. Compaction properties of till/GLD blended in the field, and 95/5, 90/10 and 85/15 blends carried out in the lab was determined using standard proctor compaction test. The compaction energy was 2.65 J*cm-3 according to the Swedish Standard SS 027109 (SIS, 1994) and was obtained by filling the column with three layers of material, compacting each layer with 25 blows with a Proctor hand hammer.

Figure 1 Loader with a crushing bucket

Figure 2 Mobile Asphalt Plant

A hydraulic conductivity test was carried out according to the Swedish standard (SIS, 1989) using Darcy's equation. Water was pressed through the column from below and collected in sampling bottles using constant water head. The amount of the permeated water was monitored by weighing. The density was calculated by weighing and water content could be calculated after the material was dried at 105°C for 24h. Water retention capacity (WRC) was measured on sample 4:3 (n=3) and on sample 1 (n=1). The samples were compacted in cylinders and saturated from below. The cylinders were then placed on a ceramic plate, and pressure was applied using a pressure plate apparatus (Soilmoisture Corp., Goleta, CA, USA).

RESULTS AND DISCUSSION

To identify the required amount of GLD that may improve the properties of till without losing the compaction properties, proctor experiments were carried out. A maximum of 20% GLD could be mixed with till. At higher additions of GLD, the plastic behavior prevented compaction by proctor. GLD has a water content of 120 - 150 % (by weight %). Its liquid limit, w_L, is ~132 %. It means that GLD at higher water content than 132 % will transform from a plastic to a liquid consistency. Based on this, 5-15% GLD was mixed with till for further analysis. The composition of the mixes is summarized in Table 1. The productions speed of the asphalt plant was 90 tonnes/h using a mixing time of 45s. The speed could be increased. The loader's capacity was 180 tonnes/h (mixed one time).

Table 1 The composition of the blends, mixing equipment, mixing time and the total amount generated are shown as well as the hydraulic conductivity (k), density (ρ) and water content. The results are given as mean ± SE (n=3).

Mix nr	Composition, mixing equipment, time	Total amount (tonne)	k (10^{-9} m/s)	ϱ (g/cm^3)	Water content (%)
1	10% GLD/Till A, asphalt plant, 45s	60	10.4 ± 9.4	2.0 ± 0.0	N/A
2	15% GLD/Till A, asphalt plant, 45s	30	12.5 ± 4.9	1.9 ± 0.0	21.4
3	10% GLD/Till A, asphalt plant ,2x45s	10	9.8 ± 3.2	2.0 ± 0.0	18.4
4 1	10% GLD/Till A, Loader, 1 run	30	61.4 ± 51.6	2.0 ± 0.0	19.1
4:2	10% GLD/Till A, Loader, 2 runs	30	4.9 ± 3.9	2.1 ± 0.0	N/A
4:3	10% GLD/Till A, Loader, 3 runs	30	4.8 ± 3.5	2.1 ± 0.0	N/A
4:4	10% GLD/Till A, Loader, 4 runs	30	32.7 ± 13.1	2.0 ± 0.0	19.1
4:5	10% GLD/Till A, Loader, 5 runs	30	55.7 ± 29.5	2.1 ± 0.1	16.1
5	5% GLD/Till A, asphalt plant ,45s	30	30.9 ± 31.7	2.1 ± 0.0	13.1
6	5% GLD/Till A, asphalt plant, 2x45s	30	13.7± 3.2	2.0 ± 0.0	16.4
7	10% GLD/Till B, asphalt plant, 45s	30	21.2± 26.7	2.1 ± 0.0	13.6
8	10% GLD/Till B, asphalt plant, 2x45s	30	8.17± 3.6	2.1 ± 0.1	13.8

A large difference in porosity and density of GLD and till was observed. GLD had substantially higher porosity, 83±3% vs. till 36±1%. The density of GLD and till was 1.21±0.05 g/cm^3 and 1.80±0.04 g/cm^3 respectively. The density for all blends was 1.9-2.1 g/cm^3. The average hydraulic conductivity of the blends was 3x10^{-8} m/s. It is a substantial decrease compared to till without additives that generated a hydraulic conductivity of 3.9x10^{-7} m/s (Table 1). The results indicate that longer mixing time may decrease the hydraulic conductivity. Only for Mix 4:4 and 4:5, the opposite applies. It is hypothesized that the multiple mixing times resulted in the inclusion of coarser till material from the ground in the blends due to the mixing technique (loader) causing the increased hydraulic conductivity. A decreased particle size of a material is usually correlated to a decreased hydraulic conductivity (Sivapullaiah et al. 2000; Benson & Trast 1995). Mixing 10% GLD with till having a silt content of 30% is sufficient to achieve a hydraulic conductivity of 10^{-8} -10^{-9} m/s (Table 1).

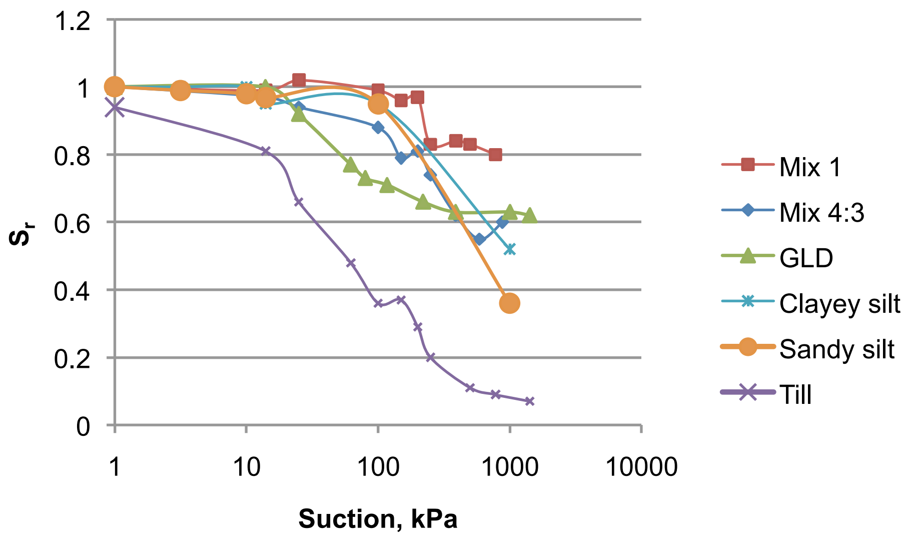

Figure 3 Water retention curves of Mix 1, Mix 4:3, GLD, clayey silt, sandy silt and till.

The water retention capacity for both the tested mixes was high (Fig. 3). Mix 1 and Mix 4:3 were of the same composition (10% GLD) but were blended with different techniques (asphalt plant respectively crushing bucket). Mix 1 blended with the asphalt plant had higher water content (*w)* and lower dry density compared to Mix 4:3, blended with the crushing bucket. It also had higher porosity. One hypothesis is that Mix 1 has undergone more intensive mixing resulting in different physical/geotechnical properties compared to the less disturbed Mix 4:3. The results indicate that intensive mixing of GLD releases bounded water. It increases the porosity and the *w* whilst the dry density decreases. A greater WRC can then be achieved. It has previously been shown that water content at field capacity (-10 or -33 kPa) is affected by macroporosity and structure (Sharma and Uehara, 1968). On the other hand, the water content at the wilting point (-1500kPa) is not dependent on the structure since the majority of the water is held with adsorption (Aina and Periaswamy, 1985). This may be the reason for the difference in WRC between Mix 1 and 4:3 decreases at this suction.

To enable the use of GLD as an additive, the factors affecting the retrieval of the finished product should be understood. Sufficient mixing could be achieved with both the loader and the Mobile Asphalt Plant. Comparing the compaction properties of the tested samples, it shows that the amount of GLD influences the degree of compaction. The 5% GLD blend achieved the highest degree of compaction, i.e. the mix that could achieve the highest dry density and lowest porosity and water content. The amount of GLD in the mix and the mixing energy/time that is applied to the samples are negatively correlated to the degree of compaction (Figure 4). The water content is dependent on mixing technology of the material and is negatively correlated to dry density. The mixing time may affect the properties of the blends and is correlated to the water content and silt content of the till/GLD mixtures. A longer mixing time increases the porosity of blends with high silt content whilst the opposite is noted for blends with low silt content. Using a till with high silt content can, therefore, increase the production process speed and efficiency. To obtain a product suitable for sealing layer purposes, the observed variations of the feed materials (GLD and till) has to be taken into account and the proportions and mixing energy should be adjusted thereafter. A guidance manual for end users is currently under construction.

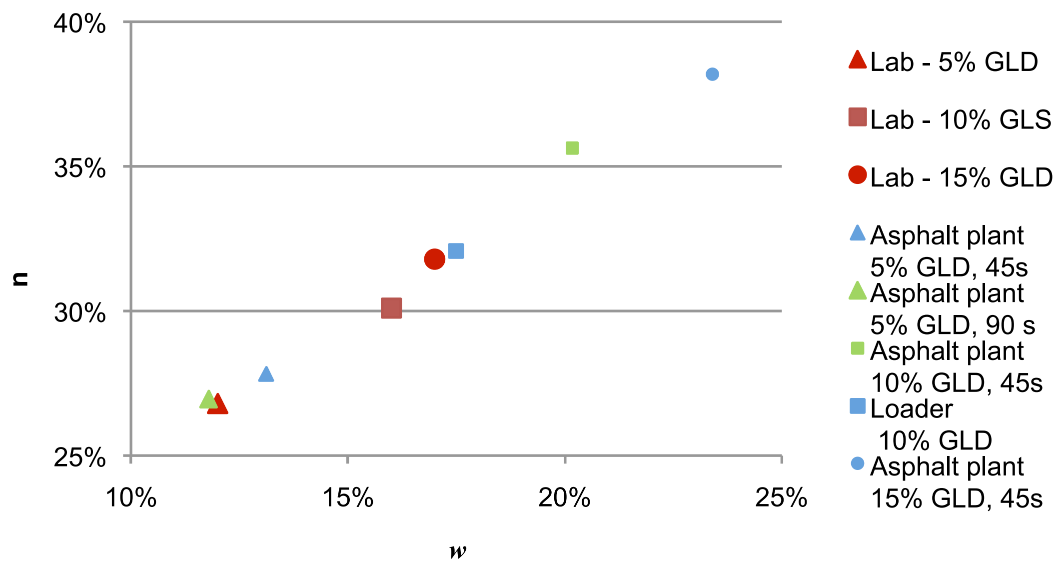

Figure 4 Correlation between water content and porosity of till/GLD samples.

GLD addition as a remediation method is a viable option and may generate decreased costs, better result or both compared with traditional remediation solutions. An assessment of transport economics, transport logistics, handling and management and other surrounding cost have been published (Mácsik and Maurice, 2014). The largest costs are concerned with transportation distances and the mode of transportation. The report showed that using GLD as an additive (addition of 10%) to till available close to the remediation site, is an economical alternative to consider if the distance to till that fulfill the requirements for sealant material is larger than ~10 miles and assuming GLD can be obtained within a reasonable distance (maximum ~500 miles).

CONCLUSION

The aim of the project was to produce mixes of till and GLD, with a hydraulic conductivity lower than 10^{-8} m/s and a high water retention capacity. This study shows that it is possible to produce homogenous mixtures under field conditions and achieve a material that can qualify as a sealing layer. Till blended with 10% GLD by using an asphalt plant showed a higher water retention capacity than till without addition of GLD, but also higher than sandy silt and even clayey silt. This is partly due to highly water saturated conditions in the compacted till/GLD mixtures. Water retention capacity and hydraulic conductivity are related to the mixtures porosity/dry density. Thereby the compacted Till/GLD blends dry density is a good measure of their function as a liner. The quality of the till, such as particle size and water content, as well as the quality of the GLD, such as water content and liquid limit, are important factors influencing the compaction and the hydraulic conductivity of the Till/GLD mixture. The amount of GLD and the mixing energy should be adjusted depending on the geotechnical properties, mainly particle size and water content.

ONGOING RESEARCH

This pilot-scale experiment creates the basis for the remediation of a part of a former mine (4.5 hectares) with a sealing layer made of GLD/till that will take place in 2015. A guide on how to design a sealing layer of till and GLD including mixing techniques, recipes, economics, etc. is currently under process and will be published during 2015. Another pilot scale experiment has been set up where the selected proportion (10%) of GLD/till has been used (based on this current study) to construct a dry cover system to simulate the mine aimed for remediation. The cover system will be monitored during the next five years and is funded by Boliden Minerals and Vinnova.

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