Post-installation assessment of the quality of a novel heap leach pad liner

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ABSTRACT: A novel heap leach pad lining system was scheduled to be installed in Alaska during summer and early fall months. Construction was delayed and required completion in the winter at temperatures of -10ºC in snow and ice conditions. The liner was a double reinforced polypropylene liner with a flat sloping floor and 2H:1V side slopes intended to contain the pregnant solution as well as the ore. At the end of construction questions arose concerning the quality of the lining system as expressed b y the state regulators. An independent assessment of the liner was performed to evaluate the liner's installed quality. The initial cause for concern, the steps that were taken to confirm the quality of the lining system, the responses of the regulators to the final project report, and the performance of the lining systems over two years of operation are reported.

1 INTRODUCTION

The mine is a remote gold mine: the closest road-accessible community is Fairbanks over 300 miles away.

The climate is sub-Arctic with average winter temperatures of -7°F to 20°F. The mining and construction season extends from approximately the end of May to mid September The heaviest rainfall month is September when rainfall averages 8.3 inches.

The central feature of the gold mine was an approximately 16 ha heap leach facility. built into the side of a hill, using the hill as the foundation for the upland embankment with engineered embankment to form a downhill side of the facility. What made the leach pad novel was a deep solution trough (Figure 1) across the lower end of the pad that would store the leachate.

Figure 1. Solution trough at low end of leach pad.

The heap leach pad itself was a double lined facility with a leak detection recovery system between the two liners. The primary liner was 0.045 in. reinforced polypropylene underlain by a geonet and a 0.036 in. reinforced polypropylene secondary liner. The heap leach pad and dam is a zero-discharge system without a spillway or outlet.

When the project fell behind schedule, the State was concerned that the onset of winter would prevent complete construction of the facility but that the company needed the complete facility in order to meet its financial commitments. The State was concerned that financial pressures might cause the company to cut corners during construction. These concerns were exacerbated by a poor relationship between the State and the company, and between the State and the engineer.

Further concern occurred after an inspection found statements in the quality assurance log that indicated upper management may have been pressuring the company to complete installation of the liner regardless of the weather. In mid-September after temperatures fell below freezing and snow began to fall, the company completed installation of both liners. The state lacked complete confidence that the facility had been constructed to specifications. This lack of confidence was, in part, because of the poor relationship between the State personnel and the consulting heap leach design engineer who also oversaw the quality assurance program, and also because construction ended during difficult winter conditions. For these reasons, the State required that the company hire a third party consultant to audit the quality assurance records to assure the State that there were no irregularities in construction.

2 QUALITY ASSURANCE AUDIT

The review process consisted of three phases:

- To review project specifications, drawings, and related quality documents to define the quality of installation targeted.
- To review all construction, test result, and quality documentation to define what had been provided
- To visit the site to see the quality of the actual installation.

2.1 *Project documents*

2.1.1 Project Specifications

The Project Specifications were primarily written for a high density polyethylene (HDPE) geomembrane, or a generic reinforced geomembrane, but not specifically for reinforced PP geomembrane that was actually selected. Not surprisingly, the Project Specifications were somewhat incomplete for a reinforced PP geomembrane - for example, there was no minimum thickness requirement for polymer over the reinforcement. The selection of a PP(R) geomembrane for the project was acceptable. While the specifications required a 0.45 mm thick second geomembrane and a 0.76 mm primary geomembrane the installer requested that they be approved to supply 0.91 mm and 1.14 mm reinforced PP geomembrane respectively. These products would themselves offer a significant improvement in basic liner quality. PP is easy to seam at low temperatures, it has a low thermal expansion (contraction) coefficient, it is not susceptible to stress cracking, it is tough, and it has a high friction coefficient. While PP itself does not have a high puncture strength it more importantly has a high puncture strain. A high puncture strength is provided by the polyester (PET) reinforcement. Even so it would be necessary to ensure that the geomembrane was fully supported by the subgrade.

An Action Leakage Rate through the primary liner of 400 lphd was required which is reasonable.

The requirements for conformance testing of supplied material each 10,000 m^2 was more than adequate. The requirement to seal cut edges of reinforced material (on the upper surface, exposed to leachate) was properly included. The required frequency of field seam testing (each 150 m) was acceptable.

2.1.2 *Project Drawings*
The drawings showed a double geomembrane lining system separated by a geonet. There were no penetrations through the geomembrane. The proposed panel layout plan was acceptable, except in the riser pipe valley up the side slope where the seams were not shown to be in line with (up and down) the slope.

2.1.2 *Construction Quality Assurance (CQA) Plan*
There was no separate CQA document for this project. This was a significant omission since many of the actions required by the CQA team are not described in the Project Specifications. The degree of CQA performed would thus be limited by the project specifications (written for both HDPE and a reinforced geomembrane, and not specifically for a PP reinforced geomembrane), the knowledge and experience of the CQA firm, and the degree of cooperation between the CQA firm and the installer.

2.2 C*onstruction, QC, and CQA documentation*

2.2.1 *PP resin certificates*
The PP resin was manufactured by Montell then shipped to another party for compounding with UV protection, antioxidant, and processing aid additives. Two examples of Montell's resin QC certificates were provided, one for a product Hifax CA204IC Black, and the other for a product Astryn CA731GC Black. The CA731 is a geomembrane resin, but the CA204 is a roofing membrane resin. It was not possible to get any additional information on the base resin provided to make geomembrane for project, other than verbal assurance that the CA731 resin was used. Certification was provided that no reclaimed polymer was used to manufacture the geomembrane.

2.2.2 *Geomembrane QC certificates*
The Manufacturer's QC data were generated, not in their own laboratories, but by an independent testing laboratory that had been accredited within the Geosynthetics Accreditation Institute - Laboratory Accreditation Program. Tests were performed on every fourth roll which, at every 1,200 to 1,500 m^2, was well within the Manufacturer's stated QC testing frequency of every 2,000 m^2. All specifications were easily met and with standard deviations in mechanical strength parameters of less than about 5% of the mean value. This showed acceptable material consistency.

Only one roll did not meet specifications, dropping marginally below the ply adhesion specification of 66.7 N - it was 64.4 N. However, this was not considered to be a serious concern.

2.2.3 *Geomembrane panel fabrication QC certificates*
The geomembrane panels were fabricated by seaming three individual rolls together. The Engineer required fabricated panels to be conformance tested at an independent laboratory for geomembrane properties and fabricated seam properties. Tests were performed at another GAI-LAP accredited geosynthetics testing laboratory, at an acceptable frequency of about every 10 panels, approximately every 10,500 m^2, essentially as required by the specifications (each 10,000 m^2). Each fabricated seam was tested. Four of the primary geomembrane panels had one seam that was marginally lower (minimum 3379 N/m) in peel strength than the Manufacturer's specification (3502 N/m), but all far exceed the minimum project specification of 1751 N/m.

Two of the fabricator's QC certificates showed comments concerning flaws that had been observed during the fabrication process. Some of these flaws were repaired in the fabrication plant. Others were identified for repair in the field. However, there did not appear to have been any specific written information to the field crews of the types and locations of the flaws.

2.2.4 *Geomembrane inventory record*
The fabricator generated complete records identifying which roll numbers were used in the fabrication of which panel number. Spot cross checks revealed no discrepancies.

2.2.5 *Construction Records*
Due to the delayed installation schedule, special cold weather, (> -25ºC and < 5ºC) welding procedures were instituted; one peel specimen from the beginning and end of each seam.

To minimize costs, the engineer relied on some of the data generated by the installer rather than generate their own documentation. The installer's data were carefully reviewed and approved by the engineer, but there was no well-defined indication of the review and acceptance of such documentation.

2.2.6 *Subgrade Surface Acceptance*
The subgrade surface was correctly accepted in units upon which the next segment of geomembrane would be laid. The subgrade of all 316 panels of secondary geomembrane was accounted for.

2.2.7 *Geomembrane Panel Deployment Records*
Daily Panel Placement forms were completed as part of the installer's QC program. These records identified the order in which field panels were placed, the fabricated panel roll number from which the field panel was taken, the size of the panel, and the date it was deployed.

Very comprehensive CQA data were maintained by the engineer on Panel As-Built forms. These forms showed:

- Fabricated panel roll number
- Installed field panel number
- Seamer initials
- Seaming machine number, set speed, and temperature
- Date and time of seaming
- Nondestructive test dates
- Panel compass orientation
- Adjacent panel numbers
- Destructive sample location, number, and date of passing test
- Date of final approval

Spot checks of these forms revealed a few typical omissions but, in general, they were very thoroughly maintained. Spots checks against the installer's Seam Control and Pre-Weld/Destructive Sample Field Test reports showed consistency of seam machine numbers, operators, and settings.

2.2.8 *Trial Seaming Records*
The installer reported trial seam test data on their combined QC Pre-Weld/Destructive Sample Field Test forms.

Pre-weld test data were recorded by each welder and machine combination at the start of each morning and afternoon welding shift, or once every four hours, as required in the Project Specifications. No failures were reported.

Spot checks found the trial seaming records to be consistent with dates, times, machine operator and setting records for production seaming - operators did not move from one machine to another or change machine settings during production seaming.

Peel test results were consistent with the Project Specifications and the installer's QC requirements. However several shear test results showed unacceptably low values. According to the engineer this was because 25 mm wide strips had been used for testing instead of the 100 mm. wide specimens required in the specified ASTM D751/NSF 54 test procedure. It was reported that the installer's personnel "understood" the relationship between results from testing 25 mm strips with full width gripping and 100 mm specimens with partial width gripping, however, no calibration charts were provided. Nevertheless, subsequent independent laboratory testing of seam samples removed from the installed geomembranes showed only one failure.

CQA Trial Seaming records were not generated.

2.2.9 *Installation/Seaming Personnel*
Resumes showed the installer's personnel to have extensive training and field experience, most of them working together on the same projects, often in cold environments. The Project Supervisor had installed over 400,000 m^2 of PP geomembrane.

2.2.10 *Production Seaming Records*
Spot checks of the QC Seam Control records indicated that these records were internally consistent with the Panel Placement and Pre-Weld Test records. The records showed that air lance testing was performed on all seams, including double track seams, as specified in the Project Specifications. The installer's QC document for PP geomembrane described only air lance testing. Normally double track seams are tested by pressurizing the center channel with air, as allowed for in the Project Specifications for HDPE geomembranes. This is a typical problem when trying with specifications to cover different materials.

From discussions with the project engineer, the manufacturer, and the installer it was understood that it was initially intended to perform center channel air pressure testing, but air lance testing was finally performed after some difficulties had occurred after air pressure testing a few seams. In essence, it was understood that the pin on the seaming machine that forms the air channel was scoring the adjacent geomembrane. Subsequently, when the channel was pressurized, pressure would be lost by air escaping through the score mark into and through the fibers of the reinforcing scrim. In some cases the geomembrane and scrim delaminated. Hence, to facilitate testing, and to minimize the possibility of further damaging the geomembrane during the nondestructive testing (NDT) process, the decision was made to perform air lance testing as allowed in the Project Specifications. Clearly, air lance testing would not be adversely influenced by a score mark that exposes the scrim on the inside of the air channel. Nor would such a feature be identified by conventional seam peel and shear testing unless peel testing was done at the channel edge of the seam track. Due to the toughness of PP and its lack of susceptibility to stress cracking, it is unlikely that such a score mark, in itself, would cause a significant lack of mechanical durability in the liner. However, such a score mark could allow secondary leachate or construction waters that access the air channel to penetrate the scrim, wick along it, and cause local delamination, as occurred during the air pressure test. Fortunately, since the scrim does not extend to the edges of complete rolls, and the edges of cut rolls were sealed with extrudate, it was unlikely that liner leakage would result. However, should delamination occur, that region of the seam will have lower shear and bond strengths.

2.2.11 *Seam Sample Destructive Testing*
The number of seam samples removed for independent laboratory destructive (peel and shear) testing was consistent with sampling each 150 m of seam. The engineer carefully kept records of "Quantities Accepted" with which it cross-referenced the frequency of seam sampling. The actual sampling rate in was every 115 m, well within specifications. However, only the primary geomembrane QC results were available for review. 126 samples were tested in the field before sending CQA samples to the independent laboratory. Two of the samples showed no field shear test results so were presumed to be unacceptable. However, samples were submitted for independent CQA tests and did pass those tests.

One secondary liner seam sample failed when the inner track of two of the five peel specimens were reported to have peeled. Despite this separation the strengths recorded exceed the Project Specifications, but one of these strength values was lower than the installer's QC specification. The Project Specifications required that at least four of the five peel/shear specimen pairs pass testing for the sample to be accepted. This one was properly rejected. The failing seam was sampled in each direction away from the original sample, as required, and both additional samples passed destructive tests. This information was also shown in the engineer's drawings. However, there was no indication of the type of repair or testing to, and between, the two additional sample holes in any QC or CQA documentation. No indication of a repair could be found in the QC Repair, Panel Placement, or Seam Control forms. The CQA Panel As-Built form did not show the distance between the two additional samples nor did it show or describe the type of repair. This was a significant omission.

2.2.12 *Repairs*
All repairs were vacuum box tested as indicated on the QC Repair Reports. It was a little surprising to note that, in such a hostile environment, no vacuum box failures were reported. However, this often means that failed test segments were successfully repaired and reported as if passing the test the first time.

The Repair Reports did not identify the seamer or the machine making the repair, thus identified problems could not be traced and their overall extent determined.

Unfortunately there were no CQA documents that identified the locations, sizes, and types of repairs. However, the Panel As-Built form did define the date when all testing was finished on each panel and the complete panel accepted.

2.2.13 *Record Drawings*
Prior to reviewing the record panel layout drawings the drawings maintained by the engineer on site had been reviewed. It was therefore believed that such records, having been kept by both the installer and the engineer, would lead to accurate final record drawings. The drawings identified the orientation of each panel, its number, the roll number from which it was removed, and the location of each seam destructive sample. As indicated previously, the secondary liner drawing does not show the location of the additional samples cut from the one failing seam.

The drawings did not show the location and type of each significant repair. However, contrary to the pre-installation layout drawings, they did show panels correctly oriented up and down in one awkward corner location.

2.2.14 *Daily Field Inspection Progress Reports*
Daily CQA reports for the complete installation period were reviewed and showed no significant concerns.

2.3 *Site Visit*

A one-day site visit was made in November 1996. As shown in Figure 1 the floor of the cell had been covered with soil and there was a great deal of snow on the side slopes limiting access and examination. Even at the moderately low temperature of –1ºC, Figure 2 shows there to be no excessive tension in the geomembrane. Reinforced PP has a very low coefficient of linear thermal expansion, thus minimizing concerns of extreme tension at low temperatures and excessive wrinkling at high temperatures.

Figure 2 also shows sections of geomembrane with the beige side uppermost and with the black side uppermost. The only difference between these materials is that the black layer contains carbon black for UV radiation protection while the beige side contains a hindered amine light stabilizer (HALS) UV protection package. The performance differences of these two additive packages is of no significance in this project since the geomembrane will be covered and protected from exposure to UV radiation within a few months. Interestingly it was found that as ambient temperature decreased, the black material would flash-over suddenly with ice, while the beige material did not.

Figure 2. East end of Cell. Black uppermost in foreground. Beige on top in background. Liner is not under tension.

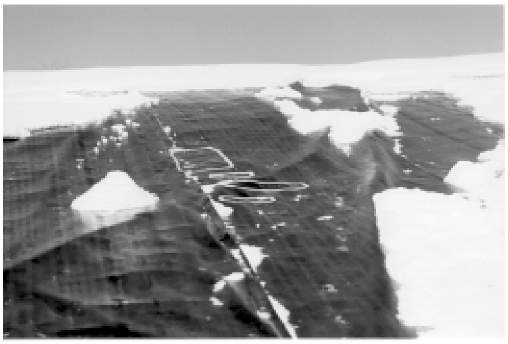

Figure 3. No tension and only small wrinkles in liner.

Seams were bonded to the outside edge Seaming details, including the seaming direction, were written on the geomembrane adjacent to the seams examined. Details and results of nondestructive testing were written adjacent to each seam.

Attempts to separate field seams by kicking the edge were made but were unsuccessful.

All cut edges of geomembrane were encapsulated with an extruded bead of PP.

Several destructive sample patch locations were cross checked on the record drawings, the Repair Record forms, and the CQA Panel As-Built forms, showing them to be correctly identified. However, four patches were not shown in the record drawings, nor was there a CQA record of them, but they were marked by the CQA staff to indicate that all testing had been successfully done.

All destructive test sample locations were identified and numbered by the engineer At all patches and seam intersections, any free flap of geomembrane had been correctly cut back to the edge of the outer seam track, prior to application of the extrusion bead, to eliminate leakage under the free flap.

The examination of the available primary geomembrane revealed absolutely no evidence of any potential problem.

- There was no bridging or trampolining of the geomembrane in any corner or at any toe of slope. Thus, the geomembrane was fully supported by the subgrade and would not be unduly stressed when cover soil was placed on it.
- Several archive seam samples were examined and all accepted production seam samples were uniform, symmetrical, had acceptable squeeze-out beads, and satisfactory air channels.
- The engineer confirmed that seams were welded right through to the end of each panel in the anchor trenches.

- It was confirmed by the engineer that the installer did not use any local labor but only used their own trained technicians. There were no changes in seamer/machine combinations after trial welds had been made.
- In the early days of PP geomembranes there were a few problems with seaming aged (exposed) material to new material. It was confirmed that no such problems were experienced on this project.

Confirmation was obtained that at temperatures below 0ºC seam peel specimens had been removed from the beginning and end of each seam. As confidence grew in the ability to make acceptable seams, samples were tested only from the start of the seam. The measured strength values were higher than the field and laboratory values due to the much lower testing temperature. Thus, since geomembrane strength increases as the temperature decreases, the bond efficiency of samples tested at the lowest temperatures had, in fact, been more severely challenged. At temperatures of –12ºC the bond had been challenged by a force of about 65 lb, while in the laboratory it had only been challenged to about 30 lb.

2.3.1 *Testing the Heap Leach Facility*

Before loading the heap leach facility the State required a hydraulic test of the facility to ensure that leak rates did not exceed design standards.

At the end of winter approximately 1.3 m of water was in the bottom of the solution trough. The State required an 11 day hydrotest.

The test called for a minimum of 150 mm of water at the west end of the facility (the end farthest away from the leak detection sump) which would mean approximately 600 mm of water at the east end above the sump. Because the test occurred at the end of winter, there was much more water. The overall average depth for the test duration was approximately 1.25 m.

The allowable leakage for a 1 m hydraulic head was 1-5 l /min.

The rate averaged 0.3 litres per day over the 11-day period of the hydrotest with a 1.25 m average head. The leakage rate was much less than the allowable rate.

For a variety of reasons, the state became concerned that the very low leakage rates reporting from the leak detection system might be evidence, not of a well-constructed system, but that the leak detection system itself may be faulty. For that reason, the state required the owner to perform a field test of the leak detection system to prove that water in the system would, in fact, report to the leak detection sump quickly.

The test was performed on the sideslope of the facility. A 1 m long section of 250 mm diameter HDPE pipe was used as a standpipe.

The test showed that water poured through the leak detection system much faster than had been anticipated a 16,200 litre water truck emptied its contents through the pipe within two hours, maintaining a 150 mm head above the primary liner. The water reported within a few hours to the leak detection sump and leakage rates then retreated to the low levels that had occurred before the test.

3 GENERAL DISCUSSION

The installer is one of the more quality conscious installers in the industry. PP is one of the most forgiving geomembranes and is most suitable for installation and application in cold climates. The design engineering company and its on-site personnel had extensive geomembrane and geosynthetic materials CQA experience. Thus, there were no fundamental reasons for there to be concern about the quality and durability of the installed double geomembrane liner. However, the reliance of the engineer on the installer’s QC documentation, some continuity gaps in that QC documentation, and the change from air pressure seam testing to air lance testing, provide gaps that made it difficult to present an absolutely positive statement that the quality of the geomembrane lining system was acceptable. The specific questionable areas were as follows:

- QC records did not allow positive confirmation that a specified or adequate PP resin was provided for geomembrane manufacturing. There were no resin QC/CQA records.
- QC records did not provide assurance that all geomembrane panel flaws identified in the fabrication plant and not repaired there had been noted in the field and repaired. There were no equivalent CQA records.
- QC records concerning the type of seam nondestructive testing performed and the results of testing were incomplete.
- The change from air pressure seam testing to air lance testing does not permit a quantitative evaluation of the extent of effective seam testing.
- The omission of seam repair type and location information at a failed destructive test location in all QC and some CQA records was of concern.

However, it was believed that all but one of these concerns could be overridden by interpolation of related data, common sense, and a knowledge of the expertise of the project parties, as follows:
- The consistency of QC and CQA conformance test results and the apparent general handling characteristics indicated little variation within the supplied geomembrane. Its welding characteristics were satisfactory. In addition, there is only one source of PP geomembrane resin in North America, unlike HDPE for which there are many. Thus, the likelihood of an unacceptable deviation in the resin is very small. The remaining possibility for concern is in the quality of the additive package provided by the compounder. However, this package is highly proprietary to the manufacturer and would not be assessed in any conventional QC or CQA test at the time of the project.
- Panel flaws were identified on one or two Fabrication QC data sheets and some repairs were made in the plant before material was shipped. Other flaws had been identified in the field and were repaired. However, there may have been a few bottom surface flaws that escaped repair. There should have been no significant penetrating flaws (holes) since they would have been observed by installation or CQA personnel during installation. There may have been a few pinholes. However, the use of a double lining system is based on the assumption that there would be a few unavoidable pinholes and construction defects in each geomembrane. Leakage through the primary geomembrane subjected to a hydrostatic head will be collected by, and removed from, the secondary lining system. Provided there is no hydrostatic head on the secondary geomembrane it is just a matter of chance if the leakage stream passes over a hole in the secondary geomembrane. Thus, the chances of a leak through the secondary geomembrane are essentially nonexistent.
- The lack of such QC data was clearly a simple failure to complete satisfactory records. Data kept by the engineer on the Panel As-Built records, and their detailed records in approving each panel, provided confidence that acceptable testing had been performed.
- The fact that air lance seam testing was substituted for air pressure testing, even though air lance testing was allowed by the Project Specifications, particularly knowing the cause for the change, was the only reason it was not possible to confidently express an opinion that the liner was an adequate installation.
- Although the details of repairs to one seam had been omitted from QC and some CQA records, it was believed that repairs would have adequately been made. The only seam destructive test failure would have received much attention and, as indicated in the CQA Panel As-Built forms, would have been adequately repaired. However, this item does define the necessity for the CQA firm to generate its own complete set of records and not to rely on the QC records of the installer.

4 CONCLUSIONS

It is demonstrated that apparent lack of concern about the quality of a lining system, and rushing to get it completed by premature deadlines, can raise concerns within the regulatory community.

Comprehensive integrated sets of QC and CQA documentation can allay many of these concerns. In the project of concern there were gaps in the quality documentation due primarily to inadequate specifications for the geomembrane actually used in the project, and due to economic constraints that put the emphasis on QC records while trying to save costs on CQA work. Nevertheless it was possible to develop reasonable confidence that the project lining system had been installed with adequate quality and durability. This was confirmed in the short term by hydrostatic testing and secondary leachate flow rate monitoring.