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Geomembrane conformance testing: two interrelated case histories

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ABSTRACT: High density polyethylene geomembrane manufactured overseas had been delivered to site where it was found not to conform to the stress cracking resistance (SCR) specification. It was rejected. The material was rejected and had to be replaced. In another project, in-plant monitoring and conformance testing was performed prior to shipping material to site. The OIT specification was not met. However, after due consideration the material was accepted. The details of these two events, their impact on the landfill owner, and their significance to construction quality assurance programs are presented.

1 INTRODUCTION

Geomembrane specifications are prepared to ensure that material supplied to a project will perform according to the requirements of the project engineer. Special performance requirements may exist in any project requiring non-conventional specifications. Alternatively conventional specifications are presented simply to ensure that a minimum national/institute standard is met. Problems can occur when manufacturers and installers assume a specification is a conventional one and do not see the non-conventional parameters before shipping the material to site. Project engineers expose themselves to potential problems when they do not ensure that materials meet specifications, whether or not they are conventional specifications, before the material is shipped to the site.

It is costly and time consuming for all parties to replace non-conforming material after it has arrived on site, particularly when the manufacturer and the site are on different continents. When off-specification material is discovered, there is then a great tendency for the project engineer to disregard the specifications and to accept the material anyway, simply to keep the project on schedule. Naturally, the installer/manufacturer would prefer not to have to replace the material. This typically negates the purpose of having geomembrane specifications and performing construction quality assurance, unless proper technical consideration of the purpose of the specifications and significance of the extent of deviation from the specifications is made. This is of major importance for high density polyethylene (HDPE) geomembranes when the parameters in question are the stress cracking resistance (SCR) and oxidative induction time (OIT), the two most important parameters of HDPE geomembranes since they control its long-term mechanical durability.

The sequence of events associated with the non-conformance of SCR and OIT parameters in two lots of HDPE geomembranes for two different landfill projects are presented, together with the reasons and activities associated with the acceptance and rejection of the materials. The costs associated with accept/reject decisions can, of course, be very high.

2 PROJECT 1: STRESS CRACKING RESISTANCE (SCR)

Single textured HDPE geomembrane was specified for the bottom double liner of a municipal solid waste landfill in South Africa. As the start of construction approached, merger activities between the proposed manufacturer of the material and another manufacturer imperiled the supply of geomembrane from North America. The installer made hurried arrangements with another manufacturer in Europe to supply the material. However, comprehensive manufacturing quality control (QC) certificates were not submitted to the project engineer prior to the materials being shipped from Europe. Thus, no check on the quality of the material could be made by the project engineer or owner before the material was on its way to the site. This represented a liability to the manufacturer. The 44 rolls of geomembrane were duly delivered to site. They were sampled for conformance testing in the USA just prior to their intended deployment Conformance testing included the single point American Society of testing and Materials (ASTM) D5397 notched constant tensile load stress cracking test.

In order to best assess the influence of the thermally bonded surface texture on the stress cracking resistance (SCR) of the basic HDPE geomembrane material it was decided to notch the specimen on the smooth side, in order that the propagating stress crack would travel through the textured surface layer on the opposite side. If the notch had been cut on the textured side, crack propagation would only have occurred in original parent material below the textured surface layer – the same as testing smooth material. The testing laboratory mentioned the difficulty of cutting a uniform consistent notch with the material supported on the textured side. Nevertheless, they proceeded. Test results did not meet the project specification of a minimum of 400 hr. This set into motion several retests at different laboratories, with notches placed in the textured side, the smooth side, and on the smooth edge of the roll, all of which generated the same consistently unacceptable results of about 60 hr. This is far too low, even compared to the standard conventional specification of 200 hr required in the Geosynthetic Research Institute GRI-GM13 specification. No effect of the textured surface was evident. However, this may have been a function of the test procedures rather than a true physical phenomenon. After about two weeks of testing the project engineer was satisfied that the material did not meet specifications, and should be rejected.

The geomembrane manufacturer had apparently not made QC SCR measurements on the manufactured material but had been assured by the resin manufacturer that the geomembrane would have more than adequate SCR, despite the fact that the verbally reported SCR of the resin, determined on cast plaques, was only about 360 hr. There is a significant difference between 360 and >400 hr. A potential source of the discrepancy is cooling the cast plaque at an inappropriate cooling rate within the ASTM D1928 standard. The standard allows for three cooling rates; quenching (very fast), 15°C/min, and 5°C/hr, all of which will generate test specimens with different degrees of crystallinity, and, therefore, with different SCRs. The quenched plaque, with minimal crystallinity, will have the highest SCR – the longest break time in the test. For more direct comparison with manufactured geomembrane performance the cooling rate used should be 15°C/minute. The slowest cooling rate will generate the highest crystallinity and, therefore, the lowest SCR. Even the intermediate cooling rate is perhaps a little fast, the geomembrane cooling from just over the melting temperature to room temperature in about 10 minutes. However, the slowest cooling rate would require about 30 hr to cool through the same range which is much further from the manufacturing cooling rate.

The complete shipment of 44 rolls was rejected, based on the low SCR. However, to its credit, the manufacturer had recognized that an SCR of 60 hr was unacceptably low and was already making arrangements to replace the material. New material was made in North America, using a different resin, but this time with a manufacturing quality assurance (MQA) monitor in the manufacturing plant. The SCR tests were performed on the first roll, on the smooth edge of the sheet and with the notch on the textured side at three different laboratories (two independent and the manufacturer's lab) to ensure the SCR met specifications. It did. The first set of specimens was removed after 449 hr without a break, and all other tests exceeded 400 hr. The material was delivered to site and installed. However, there was a significant construction delay and significantly increased costs that affected all parties.

Fortunately there was no cost to the owner for the delay itself since existing cells were able to handle the incoming waste. However, the additional MQA, engineering time, legal costs, and staff time totaled approximately $40,000US. Penalties and additional costs to the general contractor totaled approximately $14,000US, and the material replacement costs to the installer/manufacturer were approximately $240,000US. This is a total cost of about $300,000US simply because a test costing about $250US was not performed.

3 PROJECT 2: OXIDATIVE INDUCTION TIME (OIT)

The same specifications were used for a new cell at another landfill owned by the same owner, but this time with a different engineering consultant. The owner was prepared to implement the lessons learned from the first project to ensure the smooth operation of the second project.

The geomembrane for the first project was 1.5 mm in thickness, while material for the second project included both 1 mm and 2.0 mm thick material. However, the tension and load parameters used in the specifications for the first project were not changed to accommodate the different thicknesses in the second project. Thus, the 2.0 mm material easily met the mechanical property specifications while the 1 mm often did no. Fortunately, this problem was soon recognized and resolved.

This time, material manufactured in Asia, for installation by the same installer as for the first project, was approved by the owner. Close to manufacturing time it was found that the manufacturer could not produce all of the material to meet the scheduled start of installation. At the installer's request, the owner approved replacement sheet made in Europe provided the cost would not be higher. This was agreed.

As a result of his previous experience the owner required that in-plant MQA monitoring and conformance sampling/testing be performed to eliminate the possibility of nonconforming material being delivered to site again. The MQA team monitored the production of the sheet and its preparation for shipping in Asia. They audited the local laboratory that would perform conformance testing, to save the few days required for shipping samples to a US laboratory. The material made in Asia was acceptable in all respects, and SCR easily exceeded 400 hr. However, the material made in Europe, satisfactory in all other tests, did not meet the OIT specification of a minimum of 100 min. in the ASTM D3895 test.

When the QC test results were first presented the OIT was shown to be 101 min by the ASTM test, but when test details were more closely examined the test temperature was noted to be 180°C. Obviously, since OIT decreases as temperature increases, the specification would not be met at the proper test temperature of 200°C. When the need to perform the test at 200°C was pointed out to the manufacturer the manufacturer stated that the ASTM test allows testing at temperatures between 180 and 220°C in order to achieve test results in an adequately short time. This is so, but the standard also states that unless a specific test temperature is quoted in the project specifications the test will be performed at 200°C. Tests performed by an independent laboratory in Germany at 180, 200, and 210°C showed a standard OIT of over 200 min. Tests performed by an independent GAI-LAP accredited laboratory and by a manufacturer's laboratory in the US, both showed the OIT to be 83.7 min. The German laboratory acknowledged that a systematic testing error had been made.

The project specifications also included a 400 min specification for the HP-OIT. This test is more appropriate if the antioxidant (AO) package contains hindered amine light stabilizers (HALS). The HP-OIT was measured and found to be 215.9 min, again below specification. Therefore it was clear that the specification was not met. Consequently, the question of whether or not to reject the material was raised again. The project engineer was quite prepared to reject the material.

However, the geosynthetics QA consultant to the project engineer believed that a satisfactory case could be made for acceptance of the material, but acceptance would have to be thoroughly and technically justified to the project engineer and the owner. This would involve generating supporting information and data on the resin and the geomembrane itself. However, the project engineer was not prepared to accept the additional cost of performing this study. The installer, in conjunction with the manufacturer, offered to cover the costs. Sensitive to the potential for a conflict of interest, the QA consultant received approval from the owner and project engineer to proceed with the study funded by the installer/manufacturer.

The independent German laboratory demonstrated that the material met the German Federal Institute for Materials Research and Standards (BAM) OIT specification (1999) of 20 min at 210°C. This raised the question of the equivalence of the GRI and BAM specifications and the basis of their development.

According to Hsuan and Koerner (1999) both the standard and HP OIT specifications were generated by testing a number of commercially available HDPE geomembranes and finding that most had OIT exceeding 100 min while two had OITs considerably less than 100 min. The two low ones also had significantly lower HP-OIT values than the others. Hence the OIT specifications were arbitrarily set at 100 and 400 min respectively. In Germany Mueller and Jakob (2000) evaluated the long term (10,000 hr) elevated temperature hydrostatic pressure performance of HDPE pipe resins against OIT values and determined that 20 minutes at 210°C was the required specification. Both GRI and BAM have minimum retained OIT values after specific thermal aging treatments. Thus the GRI specification appears to be more empirical than the BAM specification which is based on mechanical durability.

An inverse linear relationship between OIT and temperature over the temperature range of interest is confirmed by Figure 1 extracted from the ASTM D3895 standard.

Another guide to the practical acceptability of the geomembrane was the fact that the German resin (Resin E) is the European equivalent of the manufacturer's North American resin (Resin F), except that Resin F has 50% more of the same AO additives as Resin E, specifically to meet the more demanding North American GRI.GM13 specification. The associated stress cracking performance concern was somewhat alleviated by the fact that Resin F has an SCR of well over 200 hr. This, there was some support for the suitability of Resin E. In addition the

BAM had previously certified the use of Resin E for use in natural gas distribution piping.

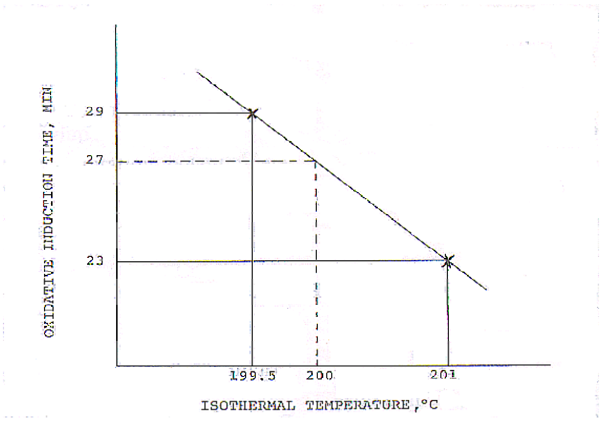

Figure 1. Change of OIT with temperature (ASTM D3895)

The practical significance and meaning of the OIT test data overall required consideration particularly since the geomembrane was to be covered in service and would not be exposed to sunlight and high temperatures. The concern was that the OIT test, performed at 200°C does not necessarily reflect the performance of the material at much lower service temperatures because the AO additive packages, proprietary to each manufacturer, contain a number of different chemical components. This is demonstrated in Figure 2 for four typical components of AO packages added to HDPE geomembrane – hindered amine light stabilizers (HALS) operate up to 130°C, phosphites above 150°C, hindered phenols over the complete temperature range, and thiosynergists up to 180°C. Therefore, depending on the composition of the AO package the performance at the OIT test temperature may bear no relationship to the performance at service temperatures: OIT may be acceptable but there may be little protection at service temperatures. Conversely, there may be adequate protection at service temperatures but OIT may be unacceptable.

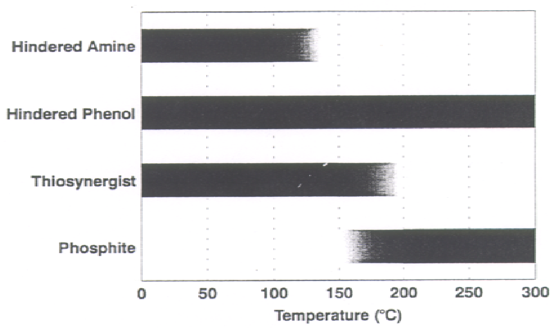

Figure 2. Effective temperature ranges of AO components (Fay and King, 1994))

The primary objective then was to demonstrate that the OIT of 83.7 minutes exceeded the BAM specification at 200°C, thus requiring a temperature shift of the 20 minutes at 210°C to 200°C. The German and US testing laboratoies had generated significant OIT/temperature data on HDPE geomembranes manufactured from different resins including Resin F. Results of testing Resin E and Resin F were plotted (Figure 3) to generate typical temperature/time relationships. Note that the OIT values for Resin F are higher than those for Resin E, as would be expected with its higher AO content. Both resins have significantly higher OIT values than the BAM specification at 210°C , which is encouraging. Then, as shown in Figure 4, when the slope of the line for Resin F is applied to the BAM specification of 20 min at 210°C the OIT at 200°C becomes 87 min. When the slope of the Resin E curve is applied it becomes 57 min, for an average of about 72 min. Thus, the measured value of 83.7 marginally exceeds the equivalent BAM specification of 72 min. This provides a technical basis, exceedance of a recognized national specification, on which to recommend acceptance of the geomembrane

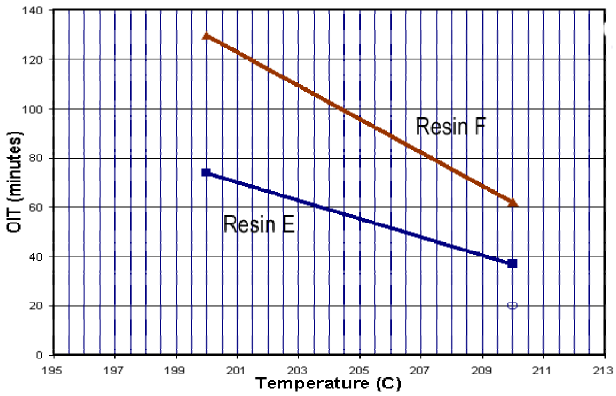

Figure 3. Measured OIT with temperature

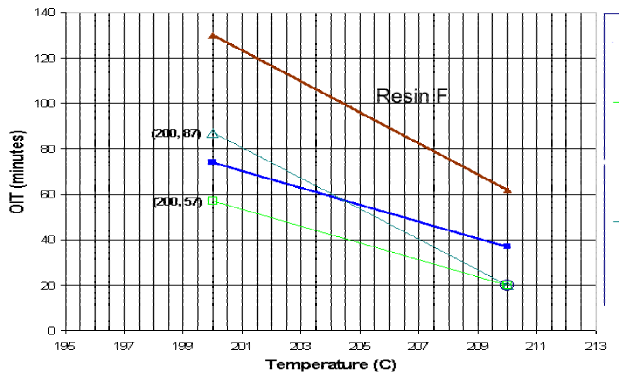

Figure 4. BAM OIT equivalence at 200°C

The fact that the geomembrane was not to be used exposed was also favorable for acceptance of the geomembrane. The recommendation to accept the material was made to the project engineer. The material was accepted. Thus, the trauma, expense, and wasted time associated with a rejection of the material were avoided, without compromising the practical performance of the lining system.

Even though the manufacturer avoided the costs of replacing the liner, the cost of making a satisfactory case for acceptance that would withstand possible public scrutiny was significant when compared to the cost of taking a little time to read the specifications (test methods and values) and performing the appropriate QC/QA conformance test.

Despite receiving approval from the project engineer and owner to be contracted to the installer for this task, the QA consultant was still concerned about the possible perception of a conflict of interest. Naturally, when working for a client arguments are unavoidable tilted within one or two "standard deviations" towards that client's interests. So, there was an opportunity to present an argument favorable (within this gray area) toward the installer/manufacturer, while previously the arguments would have been favorable, but within the same gray area, toward the owner/engineer. Hence the reason for seeking a respected national standard/specification that could be used as a benchmark, rather than just expressing an opinion. The fact that the question of the need to reject the material was introduced by the QA consultant while under contract to the project engineer somewhat justified the unusual approach. Clearly, the installer could have hired another consultant, but this would have required time for the new consultant to become familiar with the project and the situation.

These events graphically demonstrate the importance of hiring a thoroughly knowledgeable CQA consultant, whether that is the project engineer, or a specialist CQA firm. While the project engineer is familiar with his design objectives, the engineer is typically are not a geosynthetics expert. Thus, it is often advantageous to hire a specialist geosynthetics CQA firm for its expertise and to provide a second opinion. However, in developing countries this may not be feasible, in which case, and as was done for this project, a specialist CQA consultant can be contracted to guide the project engineer through events requiring the additional expertise. However, such events are often difficult to recognize without the additional expertise in the first place!

It can be debated long and hard as to whether the project engineer should have been directly responsible for generating the information on which to base his decision on acceptance or rejection of the OIT data, or whether it was an appropriate step for the engineer to require the installer/manufacturer to provide adequate information.

4 DISCUSSION

It is evident that geomembrane material specification must be very clearly prepared, indicating the test methods to be used and the minimum or maximum specified values. The specifications for one project should not be used for another without checking that they are appropriate for the type of PE geomembrane to be used – thickness, textured (single or double), same density range. It is unquestionably incumbent upon the installer and manufacturer to thoroughly read and understand the specifications and to provide the requested parameter test results. If specifications seem unusual or inconsistent they should be queried well before material is shipped, even before material is manufactured. It should not be assumed that the specification is "just another standard specification"

For large orders, for material in critical applications, and for material being shipped overseas, it is to the benefit of all parties to ensure that QC certificates and test results are issued, carefully reviewed, and accepted. Only the CQA firm and project engineer might benefit from the additional time required to resolve a delivery of nonconforming material, although this would be negated if the material was manufactured and shipped while they were on watch.

When geosynthetics CQA, or CQA of any type, is being performed it is of no value if the practitioners are insufficiently experienced. Any potential problem must first be recognized, which it will not be if the monitors are inexperienced. Then the proper actions must be taken. This requires even more experience and technical knowledge. It is a major error for the material to be accepted because "well, it is here now, and it will take too long to replace". The purpose of having a specification in the first place is thus voided. It is equally wrong for the material to be rejected out of hand simply because it is 5% out of specification. This could happen with an inexperienced CQA firm. Quite often a recognized lack of experience is countered by seemingly making the tough decisions – incorrectly 50% of the time. There is nothing incontrovertible about the parameters used in most specifications. However, it is equally wrong for a manufacturer to ship material that is known to be 5% out of specification, assuming that it will likely be accepted. This is the reason for having QC certificates, and for requiring that they be delivered before the material is shipped from the manufacturing plant. It is to the benefit of all involved.

When a material is out of specification it is the responsibility of the CQA firm, and the reason why it has been hired, to determine whether the discrepancy really is reason for rejection of the material and all the legal, financial, administrative, and scheduling consequences that might ensue. It is an awesome responsibility. For instance a geomembrane may well be specified the same whether it is to be covered or uncovered, and whether it is to be installed in very cold or very warm environments. A specification such as the GRI.GM13 specification (actually a warrant rather than a specification) is prepared to cover a typical worst case situation, so a lesser situation may not require such "extreme" specifications. For instance, a liner constantly covered by running water in a warm environment may achieve a maximum temperature of 25^{o}C, but the exposed material at the top of the slope may achieve 85^{o}C. Theoretically, the underwater material does not require the same high OIT and SCR as the exposed material. Therefore, if some of the delivered material is deficient in either of these parameters it may be usable underwater on the floor, rather than on the exposed slopes. Clearly this requires a very reasoned decision. Conversely, knowing that operating conditions may be significantly different in different locations of a project, the specifications could be prepared differently for the different locations.

Unfortunately, no-one is an instant expert - we all have to go through the learning process. This is certainly so in developing parts of the world, but these areas can learn quickly from others who have previously learned the hard way by making mistakes. Thus, the use of a geosynthetics consultant to guide the project engineer is a very sensible approach to take. However, it is interesting to note in both of these projects that the basic errors were not made by the project engineers little experienced with geomembranes, but by the very experienced geomembrane manufacturers who did not perform their own QC tests or who did not perform them according to the project specifications!

5 CONCLUSIONS

- Geomembrane specifications must be properly prepared by the project engineer.
- Geomembrane specifications must be properly read and, in cases of doubt, clarified by the installer and manufacturer.
- Before shipping materials to site the geomembrane manufacturer must perform the specified tests and ensure that the specifications are adequately met.
- Before receiving materials on site the owner and project engineer must review and approve QC certificates and MQA test results.
- Any nonconforming test results must be carefully and knowledgeably considered before a final decision on acceptance or rejection is made.

6 REFERENCES

BAM 1999 *Richtlinie für die Zulassung von Kunststoffdichtungsbahnen für die Abdichtung von Deponien und Altlasten Sonderheft 1/99*, Bremerhaven, Germany, pp 20 and 22.

Fay, J.J., King, R.E. III 1994. Antioxidants for Geosynthetic Resins and Applications. *Geosynthetic resins, formulations and manufacturing*, Y.G. Hsuan and R.M. Koerner (ed), GRI Conference Series, Philadelphia, USA, pp 74-92.

Hsuan, Y.G., and Koerner, R.M. 1999 Rationale and Background of the GRI-GM13 Specification for HDPE Geomembranes, *Geosynthetics '99*, IFAI, Roseville, MN, pp 385-398.

Mueller, W., and Jakob, I., 2000. Comparison of Oxidation Stability of Various Geosynthetics, *Second European Geosynthetics Conference*, Pàtron Editore, Bologna, Italy, pp 449-454.

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