The Future of Geomembrane Installation: Utilizing Smart Technology & Data Acquisition to Enhance Installation Standards, Project QC/QA and Reporting

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ABSTRACT

Thermoplastic Polymer Membranes such as HDPE are welded or seamed together in the field with the use of heat and pressure. During this process the material is heated at the surface to a temperature where the structure begins to melt. External pressure is applied, and the result is a stable, uniform connection. Controlled seam velocity (speed) assures that the resulting weld is consistent along the entire length of the seam. It is these three critical parameters: Temperature, pressure and speed that must be determined and monitored to assure consistent welding performance and produce high seam quality.

Hot wedge welding utilizes a hot wedge that is passed between the two layers of geomembrane to be joined together. The surface area of the two membranes is melted by the wedge and then immediately pressed together by a set of Pressure rollers that apply a predetermined pressure based on material composition and site conditions. These pressure rollers usually also act as a drive system and are controlled by a drive motor to adjust the speed of the welding process.

Hot wedge welding machines currently allow for operators to pre-set welding parameters. However, these systems may not be able to adjust to changing site conditions (ex. voltage variance) or allow for monitoring of welding pressure.

Closed circuit technology makes it possible for machines to self-regulate and maintain pre-determined values with changing site conditions. These systems can also be capable of monitoring pre-defined ranges (hi-low) of all critical welding parameters and provide real time alerts to the operator when there is a deviation in any of these fields.

Finally, this new generation of smart welding technology can be equipped with data acquisition, which continuously records and stores all three critical parameters, Speed, Temperature and Pressure. This data is then easily transferred on-site (via on-board LAN) to a smart phone, tablet or computer to allow operators and inspectors immediate evaluation in easy to read graphs and tables. The operator can also easily transfer this data (via cloud) to other team members in remote locations. This data can then be downloaded in .csv format for further processing or can be utilized in pre-formatted pdf reports.
INTRODUCTION

The advancement of synthetic polymers has provided enhancements in both quality and availability of construction products that are used for civil and environmental applications. In particular, Geomembrane development and usage has increased significantly for projects involving water retention, lining and capping non-hazardous and hazardous wastes.

Thermoplastic Polymer Membranes such as high and low-density polyethylene (HDPE and LDPE) are manufactured geomembranes that are highly resistant to chemicals and offer exceptionally low permeability values for water vapor and organic constituents found in landfill leachate. Both types of membranes are very chemically stable and as a result, are not typically glued or taped together when seaming subsequent panels. Welding thermoplastic membranes together involves melting the subsequent membranes and controlling the rheological process of the melt flow with applying external force (Saechtling et. al. 1998)

Thermoplastic Membranes are welded or seamed together in the field with the use of heat, speed and pressure. During this process the material is heated at the surface to a temperature where the structure begins to melt. External pressure is then applied, and the result is a stable, uniform connection and high seam strength. Controlled seam velocity (speed) assures that the resulting weld is consistent along the entire length of the seam. It is these three critical parameters: Temperature, pressure and speed that must be determined and monitored to assure consistent welding performance and produce high seam quality.

AUTOMATIC WELDING MACHINES

Automatic welding machines are available with either hot air or a hot wedge serving as the primary heating component (Figure 1). While both types can be used to weld or seam thermoplastic membranes, this technical review will focus on Hot Wedge systems. Additional information on welding methods and systems can be found in the following technical guidance document: EPA/600/2: Inspection Techniques for the Fabrication of Geomembrane Field Seams.

The primary distinction of automatic welding machines is the fact that they are self-propelled. All automatic welding systems utilize a set of pressure (or squeeze) rollers that also serve as the primary driver system to advance the unit. In addition, some automatic welding machines can monitor welding pressure and provide immediate feedback to the operator during the welding process.

Hot wedge welding machines currently allow for operators to pre-set welding parameters. The wedge is typically heated to a temp of 650-780°F and passed between the two (2) overlapping membrane layers to be connected. A series of contact rollers is used to assure consistent surface contact between the membranes and wedge. Squeeze rollers provide immediate pressure as soon as the membranes pass over the wedge to provide instantaneous fusion of the layers. These rollers are set to a specific pressure that is predetermined by the type of material that is being welded and site conditions. The final welding parameter that is controlled by automatic welding machines is the speed. The pressure rollers provide drive for the unit and assure that the machine maintains consistent speed and performance.
While it is convenient for all three (3) critical welding parameters (temperature, speed and pressure) to be integrated into one system, these machines may or may not be able to adjust to changing site conditions (ex. voltage variance) or allow for monitoring of welding pressure.

ADVANCEMENTS IN AUTOMATIC WELDING MACHINES & SMART TECHNOLOGY

Closed-Loop Circuitry and Digital Technologies

Closed-loop control technology (also called a feedback system) is now being utilized on some automatic welding machines to self-regulate and maintain pre-determined values with changing circumstances. For example, field seams can often run several hundred feet in length and there will likely be a voltage change (drop) as the machine progresses farther from the power source. A simple Open-Loop circuit system allows data to only flow one direction and with this system, voltage loss could impact wedge temperature and speed of the unit without the operator's acknowledgement. This in turn, could result in welds that are not seamed within the predetermined test weld parameters and could lead to potential failure within the weld itself when required destructive testing is conducted.

Closed-loop control circuitry allows data to flow to a controller (ex. PLC) to provide immediate feedback from sensors when changing conditions occur. The controller reads these electronic signals and determines if the current condition is acceptable. This is the essential element of a close-loop operating system, as corrective actions can now be applied per the controller's instruction when necessary. In the example above, an automatic welding machine that operates with a closed-loop system would make the internal adjustments to assure that both the preselected temperature and speed are maintained throughout the entire length of the seam weld.

Digital technology is now also being utilized on some automatic welding systems as an enhanced, easier to operate user interface (figure 2). This technology also allows for advanced
intelligent communication modules that are capable of monitoring, recording and storing critical machine data and welding parameter values at preset intervals.

Figure 2 Leister Geostar Welding Machine with Digital Interface displaying and easily controlling welding speed, temperature and pressure

System Monitoring, Data Recording and Reporting

Prior to daily welding activities, operators first perform test welds to assure that the automatic welding machine is set up properly to achieve satisfactory results with current site conditions. It is at this point the operator will determine speed, temperature and pressure settings for field use. Intelligent communication modules, such as the Leister Quality System (LQS) are now being incorporated on some automatic welding machines and allow these systems to be programmed with pre-defined ranges (hi-low) and monitor these critical welding settings to assure they stay in these tolerances. Audio and visual alarms alert the operator when there is a significant deviation in any of these pre-set fields.

Furthermore, this new generation of smart welding technology allows for integrated welding data acquisition/recording at predetermined intervals. Operating in the background, LQS continuously records and stores all three critical parameters, Speed, Temperature and Pressure that the operator can immediately access. This data is simply transferred (via on-board wifi) to an easy to use app on a smart phone, tablet or computer. This allows operators and inspectors on-site to immediately evaluate each welded seam in easy to read graphs and tables (figure 3). The app also allows the operator to easily synchronize this data to a cloud, allowing other team members in remote locations to quickly access and evaluate as well.
Figure 2 Samples of welding data for seam evaluation in field
All data recorded is typically stored in "read only" format, assuring that operators and others are seeing the actual data values from the welding machine. In addition to weld parameter values, additional variable information can be recorded through the LQS system for each welded seam should the operator choose to do so. A few of these include: Machine id/serial, welder id, seam number, roll number, panel number, and site conditions (ex. outside temperature). All data can be saved in .csv format and imported into the installing contractor's project QA/QC program and submission reports. The LQS app also features the ability to populate simple pre-defined reports that are automatically saved in .pdf format.

Machine data recording is now being required in some areas as part of the installing liner contractor's QC/QA submittal package. For example, the German Welding Society (www.dves-ev.de) offers guidance and guidelines for welding thermoplastic membranes. DVS standard 2225 addresses enhanced measures that are required for field seaming geomembranes when lining landfills and other contaminated sites and specifically outlines the requirement for providing actual recorded values from the machine for speed, wedge temperature and joining force. While this standard is not yet a requirement in some other parts of the world, it should be noted that data recording and other "smart technology" has been utilized successfully for over 20 years this technology has advanced, resulting in lighter and more compact welding systems for field installations.

ENHANCED INSTALLATION STANDARDS AND FIELD QC/QA MEASURES

Monitor Welding Pressure and Adjust to Changing Site Conditions

As previously highlighted, there are three (3) critical factors for welding or seaming polymeric materials: Heat, speed and pressure. While all current automatic welding machines allow for initial set up for all 3 welding parameters, not all allow for the actual monitoring of welding pressure in field seaming operations.

The proper flow of the plasticized material is controlled by the pressure that is immediately applied after this material has been melted. Often referred to as "Squeeze", it is important to properly set and monitor this parameter. Advanced load cells are now being used in some modern welding machines that provide actual values of welding pressure during field seaming operations. Continuously changing factors on site can impact welding pressure including membrane temperature and subgrade. Utilizing upgraded load cells that monitor and report actual pressure values allows operators and inspectors to continuously monitor this critical parameter and assures that the welding pressure is consistent with the preset value established during earlier successful test welds.

Immediately Identify Abnormalities Along Welded Seams and Possible Area of Failures

It is estimated that seam leakage accounts for as much as 19% of overall leakage damage during the installation of geomembranes in waste containment facilities (Nosko et. al. 1996). Non-Destructive Testing or "Pressurized Air Channel Testing" (GRI GM6) is performed along the entire length of each welded seam to assess the continuity of the seam and minimize further Destructive Testing frequency. With many field seams extending over several hundred feet, these leaks are often difficult to identify and take time away from installation activities. By immediately accessing welding data on the seam under question, operators can quickly identify specific areas along the seam that could be the source of this issue and isolate these areas for additional testing.
Figure 3 below illustrates a leak along the weld seam that was immediately located and addressed, saving the installer several minutes in additional detection testing.

**Figure 3 – Example from seam evaluation showing anomaly with welding pressure**

**FURTHER TECHNOLOGY ADVANCEMENTS**

In addition to data recording capabilities, automatic welding machines are now starting to incorporate on-board GPS technology and enhanced augmented GPS systems. With continued developments, welding machines are now able to record 3-dimensional positioning at predetermined intervals in unison with data recording. Previously this technology would not be accurate enough (several meters of accuracy) for functional use. However, recent advancement with GNSS and mapping technology has produced systems with accuracy as precise as < 2 inches. With this capability, the operator can now produce reports with actual machine data and the corresponding positioning data (for each welded seam). This information could then be utilized by the installing contractor for as built drawings and reporting in their final QC/QA submissions packet.
CONCLUSION

Thermoplastic polymer membranes such as HDPE and LLDPE are common in civil construction and environmental remediation due to their low permeability and compatibility with various organic compounds. The three (3) critical parameters for successfully welding polymeric material are: Temperature, speed and pressure. Thermoplastic membranes are typically joined or seamed in the field utilizing automatic welding machines that allow operators to pre-set and control all 3 welding inputs.

Welding machine manufacturers are taking advantage of advancements in digital and closed-circuit technology and intelligent communications modules to provide welding systems that can monitor and warn of changing site conditions. The outcome is a more consistent weld along the entire length of panel seams, saving time and rework for the installer and 3rd party inspector. These machines are also capable of monitoring pre-set values for all 3 welding parameters and will immediately alert the operator if the actual value falls out of the desirable range.

This new age of welding machines incorporates data collection that can be accessed on-site via on-board wifi, allowing the operator to immediately evaluate each welded seam for potential anomalies. This function is especially helpful when initial non-destructive testing results in a failure on longer seams. Collected data is easily transferred from the machine in read only .csv format and can be imported into the installing contractor's QA/QC program and submitted with final project documents and drawings.

Finally, enhanced GPS and GNNS mapping technology is also now being developed in some welding machines to provide positioning data along with the recorded weld parameter data in pre-determined intervals. This information can then be utilized in CAD and other mapping programs to provide even more seam weld details (location) and a basis for as built drawings.