Critical Components of Welding Thermoplastic Membranes

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Abstract

Thermoplastic membranes comprise the largest segment of the low-slope roofing market. A critical key to their success is their ability to form a watertight seam, in the field, that will perform over a long period of time. There is a body of research that has focused on “welding windows” and formulation performance, yet critical to fabricating good seams on the roof is having a thorough understanding of cleaning procedures, robotic welding equipment and settings, ambient temperatures, interpreting test welds, and the art of hand-welding. While there is much anecdotal evidence of what can affect the ability to field-fabricate seams that perform over the long term, there is a lack of data regarding these key elements vital to the roof’s performance. The speaker will examine the critical components of proper field welding for both PVC and TPO membranes. He will discuss key differences between the two membranes and how roof consultants and roof observers can insure that thermoplastic single-ply membrane roofs are welded correctly, regardless of field conditions.

Speakers


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INTRODUCTION

Thermoplastic roofing membranes have grown to become the most commonly used roofing system for low-slope roofs. While there are several reasons for this growth, including ease of installation, low labor costs, high reflectance, and resistance to different environmental conditions, the fact that these membranes are typically installed with a heat-welded lap is key to their consideration for use. Many consider a heat-welded lap superior to one that relies on adhesives, tapes, or other bonding mechanisms.

As with any single-ply roofing membrane, the ability to form a watertight seam is paramount to a thermoplastic roof’s performance. Any deficiency in the seam creates a point of water entry into the roof area compared to those systems that are mechanically attached with plates and fasteners, care must be taken to keep the seam clean and dry, contaminants will interfere with the weld and, generally, the result is a poor or false weld.

New material being installed should be clean when unwrapped and unrolled on the job site and may not require cleaning if welding takes place in a short period of time on the same day. The cleaning requirements are much different for material that has weathered in place or gotten dirty due to foot traffic/dirt contamination. While membranes that are fully adhered using adhesives or low-rise foam typically have fewer issues with foot traffic in the seam area compared to those systems that are mechanically attached with plates and fasteners, care must be taken to keep the seam area free of the adhesive.

Regardless of installation method, there are several ways that roofing contractors can mitigate contaminating a new membrane during a project and avoid having to undertake extensive cleaning. First, roof layout and paying attention to the staging of the project are important, as is removal of any debris that can be picked up by foot traffic and contaminate the field sheet. If the job is a complete tear-off, some contractors will have one crew tearing off and working its way across the roof while another crew is installing the new roofing system behind them. This can reduce the back and forth across the new membrane if the project is properly staged. Another practice that reduces membrane dirt pick-up during a tear-off project is having the roofing crew bring a change of footwear or even utilize disposable slip-on “booties.”

While recommendations vary from manufacturer to manufacturer, one clear standard guideline should be that any material rolled out and put in place needs to be welded the same day, including welding of any detail work. This can greatly reduce any cleaning of the membrane that may be necessary prior to welding. In addition, temporarily closing seams with duct tape, black

<table>
<thead>
<tr>
<th>Type of Contamination</th>
<th>Membrane Cleaner</th>
<th>Method</th>
<th>Notes/Tips</th>
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| Light                   | TPO: xylene or naphtha; consult manufacturer<br>PVC: MEK or acetone; consult manufacturer | Clean with cloth moistened with membrane cleaner.  
Allow solvents to flash off. | • Use white terry cloth; avoid use of industrial cleaning paper cloths.  
• Colored cloths can transfer the dye in the cloth to the area to be welded and should not be used.  
• Do not over-use cloths; dispose of when dirty.  
• Do not use scrub brushes; they can damage the membrane.  
• Drying time for cleaner increases 3-5 minutes for every 10°F drop in temperature.  |
| Dirt-Encrusted          | TPO: xylene or naphtha; consult manufacturer<br>PVC: MEK or acetone; consult manufacturer | Scrub with low-residue cleaner (409®) using a mildly abrasive pad.  
Clean with cloth moistened with membrane cleaner.  
Allow solvents to flash off. |                                                                                           |
| Weathered or Oxidized   | TPO: xylene or naphtha; consult manufacturer<br>PVC: MEK or acetone; consult manufacturer | Scrub with membrane cleaner using a mildly abrasive pad.  
Clean with cloth moistened with membrane cleaner.  
Allow solvents to flash off. |                                                                                           |

Figure 1 – Summary of cleaning recommendations.
tape, caulks, etc. should be avoided when at all possible. These materials can be hard to clean off the surface of the TPO or PVC membrane and, in the long run, cost the roofing contractor time and money to clean.

Membrane that has been exposed for more than 12 hours or has become contaminated will require cleaning. If the membrane has been exposed overnight or exposed to airborne debris, foot traffic, dew, or light precipitation, the seam area can usually be easily cleaned. See Figure 1 for a summary of cleaning recommendations. Membrane that is dirt-encrusted will require the use of a low-residue cleaner, such as Formula 409®, and a mildly abrasive scrubbing pad to remove the dirt. This must be followed by cleaning with a white cloth moistened with membrane cleaner. Membrane that is weathered or oxidized will require the use of membrane cleaner and a mildly abrasive scrubbing pad to remove the weathered/oxidized top-surface layer. This should once again be followed by cleaning with a white cloth moistened with membrane cleaner. Unexposed membrane left in inventory for a year or more may need to be cleaned with an abrasive scrubbing pad and membrane cleaner, followed by a white cloth and membrane cleaner. Be sure to wait for membrane cleaner solvent to flash off prior to welding.

Membrane that is contaminated with bonding adhesive, asphalt, flashing cement, grease, oil, and most other contaminants usually cannot be cleaned sufficiently to allow an adequate heat weld to the membrane surface. These membranes should be removed and replaced.

One change regarding the cleaning of membranes is the introduction and use in recent years of low-VOC cleaners and alternatives to the standard cleaners that typically have a high solvent content. The roofing contractor must comply with solvent regulations in his or her area and use a cleaner that is compliant with the applicable regulation. While effective, care must be taken to follow the recommendations provided by the manufacturer of the membrane and the cleaner. Generally, the use of these cleaners will result in a cleaned seam area; however, they may require more scrubbing/effort for dirt-encrusted or oxidized membranes. Low-solvent-content cleaners may also require a longer drying time than high-VOC cleaners.

Regardless of the cleaner used, care must be taken to not use too much cleaner and to allow it to properly dry prior to welding. If a solvent cleaner does not properly flash off, or if the seam area is not dry after cleaning prior to welding, it will be difficult to obtain a good weld. Ambient conditions are a key variable in the time that it takes for the cleaner to dry prior to welding. When using a soap-based cleaner, the second step of using a membrane cleaner is critical, because it removes any residual film left by the soap.

Some roofing contractors will try to skip the use of soap-based cleaners for moderate to heavy dirt contamination. Using more solvent-based cleaner can cause more harm than good by forcing the dirt into the membrane rather than removing it with soap. When this occurs, the seam area can be much more difficult to weld.

**EQUIPMENT REQUIREMENTS – THE BASICS**

There are three key pieces of heat-welding equipment generally necessary for a completed job: power generation, robotic welders, and hand-welders. While some roofing contractors will hand-weld an entire project, given the advancements in robotic welding and the capabilities of robots, it is typically impractical to hand-weld large areas of the field of the roof. In fact, some manufacturers specifically discourage hand-welding for the field of the roof except for repairs or areas that are nonconductive to robotic welders.

**Power**

Regardless of the welder, the first key element—power generation—is critical to a successful installation. The generator being used must be of the proper size for the welder. A 10,000-watt minimum generator is typically required for automated welders with a 220-volt/30-amp plug. In addition, the generator should not be used to power any other equipment during welding. Generators should be heavy-duty and provide “clean electricity,” which is lower harmonic distortion of the electricity as expressed by total harmonic distortion (THD). Clean electricity, where the THD is less than 6%, will allow robots to operate more efficiently and smoothly.

Power generation is not just about the generator, but also how the electricity gets to the welder. Electrical cords should be as recommended by the robot or hand-welder equipment manufacturer. For example, the extension cord should be 10/3 gauge and no longer than 100 ft. for 220-volt/30-amp robotic welders. Use of extension cords that do not meet the appropriate specifications in gauge and maximum length can result in overheating of the cord, melting of the wire inside of the cord, or an electrical fire on the roof, and can affect the performance of the tool being used.

**Robots**

There are many different types of robotic welding machines that are used in our industry to weld thermoplastic membranes. Most of these machines have a maximum temperature between 1100º and 1148ºF (593º and 620ºC) and welding speeds that can exceed 20 feet per minute (FPM). The quality of the finished seam is affected by several different variables, including the time that the materials being fused together see a given temperature. Because of the nature of thermoplastic materials, temperature and speed are generally the two variables that roofing professionals think of when considering how the robot will attain a good seam.

While robotic welders can operate at high speeds, trying to weld a single-ply membrane at speeds in excess of 16 FPM can cause problems with the finished seam and can create safety concerns. Consider operators walking backwards towards a roof edge, cords hanging up, reduced time to correct small deficiencies, etc., and speeds in excess of or even approaching 16 FPM may seem unreasonable. Perhaps the fact that the small amount of “time” saved by using higher speeds is often offset by additional labor required to repair deficiencies is why many quality-conscious and experienced roofing contractors set robotic welders at much lower speeds.

As noted when discussing power generation, most robotic welders require a 220-volt/30-amp plug-in and the use of 10/3-gauge extension cords 100 ft. or less in length. There are robotic welders available that run on 110- to 120-volt/15-amp power that produce approximately 260 LPM of airflow. They are marketed as a solution to run off of a standard electrical outlet. Taking into consideration that a typical hand-welder needs 110-120 volt/15 amps to function properly while producing 250 LPM of airflow, there is little difference or advantage between a handheld welder and these smaller robotic welders. These lower-voltage
welders are considered by some operators as a “hand-welder on wheels” and may take additional effort to obtain a good seam. They are also limited in the thickness of membranes that they can weld, usually up to a 60-mil membrane.

Robotic welders have external weights that can be added or removed to adjust applied pressure, which facilitates getting a good welded seam. Care must be taken to use the right weight; too much weight, coupled with a faster speed, can cause wrinkling in the seam area; and too little weight does not help in obtaining a good seam. The amount of weight that is needed varies, depending on the substrate the membrane is being installed over.

There are also adjustments on most welders that allow movement of the welding shoe/nozzle, which should be adjusted so that it is not completely buried under the edge of the seam being welded. The shoe/nozzle should also be adjusted so that it is not too close to the pressure wheel.

In addition to adjustments for speed and heat, the other setting that should be “dialed in” is airflow. For most TPO and PVC seams, the airflow will be set at 100%; however, in colder conditions, the airflow may be adjusted to less than 100%.

Hand-welders
Hand-welders are generally used for detail work where robotic welders cannot be used. They are portable units that run off of a 110- to 120-volt/15-amp power supply and are used with a silicone-covered roller to apply pressure to complete welds. While a robotic welder allows the operator to enter information into the machine (temperature/heat, speed, and airflow), a hand-welder allows the operators to only set the temperature. They then must adjust the speed of their welding depending on how fast or slow they move the welder.

Temperatures on hand-welders typically will reach 1100°F (593°C), and airflow is specific to the model of welder, since different pieces of equipment have different fan motors. Power supply to the hand-welder is also critical and a minimum 12-gauge, 100-ft. length maximum extension cord should be used to power any hand-welder.

Robotic Welding – The Workhorse for the Field
When determining how to obtain a seam that will be properly formed, regardless of membrane type, operators focus on settings. There are several variables that ultimately affect the quality of the finished seam:

- Temperature
- Speed
- Airflow
- Power requirements/sourcing
- Applied pressure
- Substrate
- Ambient conditions
- Membrane thickness and type

Only three of these can be adjusted on any given project or any given day: temperature of the welder, speed of the welder, and airflow.

Speed vs. temperature setting adjustments will handle about 95% of the conditions under which a robotic welder will be operated. Most operators have experience in finding the proper welding temperature and speed settings for the project conditions. Experienced operators who seam thermoplastic membranes with great success day in and day out, understand the need to “stay inside the weld window” and have a keen understanding that speed can compromise overall job productivity. Slowing down the welder will avoid maximizing the temperature and will provide greater control of the robotic welder. Experienced operators who operate at even slightly lower speeds can avoid the need for stripping in poor seams or having to repair wrinkles in the seam, both of which can severely harm overall productivity. See Figure 2.

Previous work has been published on “weld windows,” but proper setting of a robotic welder should be dialed in each day on a project by conducting test welds to determine the proper settings for the robot. When dialing in the best speed and temperature, it is recommended that the operator keep one setting (either temperature of the welder or speed) constant and adjust only one at a time.

A typical test weld on an 80°F (26°C) day with a light wind could proceed as follows:

- Set airflow on welder at 100%, speed at 10 FPM, and temperature at 600°F (316°C).
- Conduct test welding.
- Increase temperature in 100°F (38°C) increments, conducting test welds at each temperature (e.g., 700°F [371°C], 800°F [427°C], etc.) until maximum temperature setting is reached.
- Allow test welds to cool.
- Cut a 1-in.-wide strip across the seam.
- Pull apart by hand.

A proper weld will expose the underlying reinforcement/scrim by showing a “film-tearing bond” and should be 1 to 1.5 in.

![Figure 2 – Seam wrinkles.](image-url)
Figure 4 – Scorched membrane.

wide with full delamination exposing the scrim in the weld area.

Lay out the test weld samples that have been pulled apart, and these samples will show the “weld window”—those temperatures at 10 FPM that obtain a weld that gives a full film-tearing bond. Normally, the temperature in the middle of this weld window should then be used to begin welding of the membrane. This will protect the membrane from overheating and will also avoid false or cold welds. Conversely, a test weld could be undertaken by setting the temperature to a constant, such as 950°F (510°C), starting with a slow speed, and increasing the speed to create test welds.

This procedure should then be checked during the day as ambient conditions change. Additional test welds and then adjustments to the settings for temperature and/or speed may be needed to ensure proper welds.

Hand-welding – It’s All in the Details

Hand-welders are generally used for flashings and detail work, around penetrations, for starts and stops, for T-patches, etc. Hand-welders can be dialed into the correct setting fairly quickly by an experienced operator. When considering the variables that affect welding (see “robotic welding” bullets, above), the operator must be able to adjust hand-welding for several of the variables. For example, nonreinforced membrane typically requires less heat to achieve a good weld, due to the nature of the membrane; so when welding an outside or inside corner of a curb with non-reinforced membrane, the hand-welder will be set at a lower temperature than when welding a wall flashing using the same reinforced material as in the field of the roof. See Figure 3. Another example of an adjustment that must be made is that often times the area being hand-welded becomes smaller and smaller and results in an area with a higher concentration of heat.

To obtain a good hand-weld, generally the operator must create a two-pass weld, regardless of whether he or she is welding reinforced or nonreinforced membrane. Care must be taken when using a silicone-coated roller to properly apply pressure when hand-welding a seam. The roller must remain flat on the seam area with uniform pressure applied across the face of the roller. Do not turn the roller on its edge. If the roller does turn on its edge, “stitching” can occur, which can result in voids in the seam and, ultimately, result in a failed seam.

There are differences between hand-welding TPO and PVC. When welding PVC material with the temperature settings adjusted correctly, a fine line of bleed-out will be visible on the seam area that is being welded. A certain amount of smoke will also be visible, and the surface of the lower sheet will turn somewhat glossy when heated correctly. Also, when welding PVC membrane, a buildup of residual membrane on the nozzle of the hand-welder (or robot) is fairly typical, and a wire brush will be needed to clean the nozzle.

Conversely, when welding TPO, any evidence of bleed-out or smoke is an indicator that the operator is actually overheating the membrane and needs to either speed up or turn the heat setting down. If the temperature is set too high or the operator is moving at too slow a speed, a change of color that resembles a scorch or burn will be observed at the seam area(s). See Figure 4.

Most roofing manufacturers offer pre-manufactured accessories for both TPO and PVC roofing systems that replace many field-fabricated flashing details and reduce the number of hand-welds needed for many details. For quality installations, these accessories generally save labor and often result in better-finished details.

A final consideration for hand-welding is that most welding errors are in hand-welding, with a very small number of errors caused by not having the robotic welder set properly when welding in the field of the roof. There is an art to hand-welding, and it truly is all in the details—how the operator takes into consideration the variables that affect the quality of the finished welded seam.

CRITICAL ELEMENTS – KEY TO GOOD SEAMS

Test Welds and Probing

Test welds are a necessary procedure and must be done to ensure that a good seam is being formed. Seam probing does
not negate the need for test welds. A general rule of thumb is that the contractor should take a test weld every 200-400 feet of seam welded, which is a check-as-you-go approach. While this will create a patch every two to four rolls of a 100-ft. roll, one patch every 20-40 squares of finished roofing is much better than having to strip-in several hundred lineal feet of cold-welded seam. When completed, the test welds are usually marked with the date, time, ambient conditions, and location on the roof as a good historical record of the job site conditions and seams completed.

Temporary Seals and Night Seals

The seams in the field of the roof and details should be completed each day to avoid contaminating the membrane by the use of temporary or night seals. Use of duct tape, black tape, water block, caulk, etc. only introduces contaminants on the surface of the membrane, and often either the material used or the subsequent cleaners used to remove the seal material ends up in the area to be welded. A large majority of roofing contractors avoid using temporary seals and actually do complete the field and detail seams each day. Avoiding temporary seals goes hand in hand with a keen attention to job layout, ambient conditions, sufficient manpower, and project scheduling.

Using a blunt tip probe to check welded seams in a thermoplastic roof should also be done. This will expose any skips in a welded area that must be repaired for the membrane to be watertight. Care must be taken to keep the tip of the probe blunt and not allow it to sharpen to a point. Probing is done by running the blunt-tipped probe along the seam edge; skips or anomalies in the seam are discovered when the probe can edge into the seam area.

Starts and Stops

There will most certainly be areas on any roof system where the robotic welder will need to be started and stopped, leaving unwelded areas. The operator will need to complete the weld with a hand-welder. There are certain ways to correctly address these areas when hand-welding, and care must be taken not to over-heat these seam areas. Addressing sheet layout can help to mitigate stop-and-start areas. A good practice is to have the robot operator mark stop-and-start areas on the membrane to ensure that the seam area is properly detailed and finished.

Membrane Type and Thickness

TPO membranes and PVC membranes weld differently, and the operator must take into consideration what material is being welded. PVC membranes should show a small bleed-out when welded, and TPO membranes should not show any bleed-out. Most roofing contractors will relate that “PVC membranes love heat,” and “TPO membranes, not so much, and too much is harmful,” and this is generally true. Regardless of type of membrane, thicker thermoplastic membranes will require more heat and pressure to weld than a thinner membrane of the same material. Consider that an 80-mil membrane has to heat both the cap/top surface of the underlying membrane and the core/bottom surface of the top sheet, and added together, it takes more heat to weld 80 mils of a material than 45 mils. See Figure 5.

Cold Welds

Cold or false welds are those areas of poor welds that do not obtain a film-tearing bond, and these types of welds will eventually fail. Often, failure starts as a ghost leak or leaks. If the seams are probed and no obvious seam deficiencies are found, then the seam must be tested by taking a seam cut and testing the weld to determine if it formed a film-tearing bond. If a false or cold weld is found, then check from that point both forwards and backwards to isolate where the poor welding occurred. If cold welds are found while the roof is being installed, then the roof observer or roofing contractor should check “backwards” through the previous production to isolate where the welding deficiencies started by taking seam cuts. Probing should be considered an insufficient measure to locate cold welds. Seams that have false or cold welds must be stripped in; they cannot be re-welded.

SUMMARY

As with any single-ply roofing membrane, the ability to form a watertight seam is paramount to the performance of thermoplastic membranes. A good seam should not create a point of water entry and should perform without exception for the life of the roofing system. Proficient roofing contractors have been welding thermoplastic membranes for decades and the proven long-term performance of these membranes is indicative of their ability to obtain good welded seams.

Welding of thermoplastic membranes requires attention to detail and conditions. With just a simple understanding of the variables that affect seam welding and then adjusting these variables as appropriate to properly fuse membranes together, a well-installed thermoplastic roofing system should provide long-term protection for the property owner.