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Solvent Cleaning and PE Joining Procedures – Final Report Addendum

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List of Acronyms

Acronym	Full Form
DI water	Deionized water
EF	Electrofusion
GTI	Gas Technology Institute
HDPE	High Density Polyethylene
IPS	Iron Pipe Size
ISO	International Organization for Standardization
MDPE	Medium Density Polyethylene
OTD	Operations Technology Development

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Executive Summary

This addendum reports on additional test matrices that were designed to address feedback and questions that were raised by the project sponsors during the review of the results from Test Matrix 1 in the final report. Each of the five addendum matrices had a different pipe preparation procedure to address an associated question:

- Test Matrix 2: Testing the contribution of scraping to contaminant removal
 - Scraping was performed after solvent cleaning
 - All fusions fell in the 81%-100% ductility bin
- Test Matrix 3: Testing the contribution of water washing to contaminant removal
 - Scraping was performed before water washing and solvent cleaning
 - Fusions did not consistently fall in the 81%-100% ductility bin.
- Test Matrix 4: Testing the contribution of additional solvent cleaning passes to contaminant removal
 - Scraping was performed before solvent cleaning
 - Fusions on pipe contaminated with bentonite fell in the 81%-100% ductility bin
 - Fusions on pipe contaminated with silicone grease did not consistently fall in the 81%-100% ductility bin
- Test Matrix 5: Testing of proposed best practices procedure
 - Scraping was performed after water washing and solvent cleaning
 - All fusions fell in the 81%-100% ductility bin
- Test Matrix 6: Testing of proposed best practices procedure without solvent cleaning
 - Scraping was performed after water washing
 - All fusions fell in the 81%-100% ductility bin
- Test Matrix 7: Testing the influence of solvent cleaning after scraping on fusion ductility
 - Scraping was performed after solvent cleaning
 - One solvent cleaning pass was performed after scraping (within the scraped area)
 - All fusions fell in the 81%-100% ductility bin

The addendum test results have led to the following key observations:

1. Tests where scraping was performed after contamination and water washing and/or solvent cleaning resulted in ductile bonding.
2. In tests where scraping was performed before contamination, additional solvent cleaning wipes improved removal of contamination, but did not always remove all contamination.
3. Test results where additional solvent cleaning was performed after scraping indicate that solvent cleaning is not inherently detrimental to PE fusion.

Observation 1 directly supports the recommended best practices scraping procedure given in the final report, where scraping is performed after cleaning (removal of loose surface contaminants) and fitting assembly and fusion are performed promptly after scraping to minimize the chances of contamination of the scraped pipe.

Observation 1 also suggests that the choice of cleaning solvent for a surface that is going to be scraped is not critical if scraping is performed promptly prior to fusion. This is further supported by the results of Test Matrix 6 where only a water wash was performed (no solvent cleaning) to remove the loose bentonite powder and bulk of silicone grease.

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Observation 2 reinforces the observations and conclusions in the final report where solvent cleaning was found to be inconsistent in terms of surface contamination removal. Observation 2, however, also suggest that multiple solvent wiping passes may be a valid option when scraped pipe has been contaminated. Further work on solvent cleaning technique and multiple wiping passes would be required to prove this, as the number of test runs under this scope was limited. Moreover, the tests conducted in this project only considered severely contaminate pipes with two of the most problematic contaminants: bentonite and silicone grease. The efficacy of solvent cleaning on light contamination and other contaminants¹, such as natural body oil from fingerprints or sweat, lubricants, etc., would need to be determined by additional testing.

Observation 3 indicates that the practice of solvent cleaning of fusion surfaces between the scraping and fusion steps is not inherently detrimental to PE fusion. However, Observation 1 also indicates that this practice is not essential. It is up to the operator to determine if this practice should be included in their fusion procedures. It is important to note that care should be taken to avoid the possibility of transferring contaminants onto the scraped surface via the solvent cleaning process, for example: by wiping beyond the scraped area or exposing the wipe to a dusty environment. Also, if a rough surface has been created by the scraping process, there is a possibility that the wiping tool may get snagged and leave some of its matter (fibers) on the pipe. Sealed, pre-saturated solvent wipes can help minimize exposure to a dusty environment.

Also of note is that if scraping tools with serrated blades are used, then solvent cleaning of the roughened pipe surface cannot guarantee that contamination will be removed from in between the ridges of the scraped surface.

It should be noted that in all the addendum tests, the electrofusion saddles were taken out from their individual packaging promptly prior to assembly and no cleaning was performed on them. Fittings should be expected to be in pristine condition while in the manufacturer's packaging. If a fitting becomes contaminated in the field, it should be treated in the same manner as a scraped pipe that becomes contaminated – that is, with acknowledgment that solvent cleaning may not remove all the contamination and thus rejection of the fitting should be considered¹.

Prevention of contamination of the fusion surfaces can be achieved by accomplishing three important steps:

1. Removal of all loose and spreadable contaminants (dirt, oil, grease) on the pipe (cleaning).
2. Proper scraping of the pipe promptly after cleaning.
3. Assembly of the fitting and performing the fusion promptly after scraping.

Step 1 all loose and spreadable surface contaminants are removed (cleaning) so that when scraping is performed, loose contaminants are not transferred onto the scraped surface.

Step 2 scraping is performed promptly after cleaning to minimize the chances of loose contamination settling back on the cleaned surface due to wind, static electricity, etc. Proper scraping refers to uniform removal of sufficient material (minimum scrape depth).

Step 3 the fitting is assembled and fused on to the scraped surface promptly after scraping to minimize the chances of loose contamination settling on the scraped surface. Freshly scraped pipe is the cleanest surface possible, therefore, additional solvent cleaning is not inherently necessary provided the

¹ NTSB Safety Alert, *Safety Through Reliable Fusion Joints*, SA-047, June 2015, <https://www.nts.gov/safety/safety-alerts/Pages/default.aspx>

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scraping/peeling tool was clean and no contamination was transferred or introduced onto the scraped pipe during scraping. It is important to note that touching of the fitting's fusion surface(s) and the scraped pipe/fitting stub must be avoided as oil from fingerprints may be detrimental to PE fusion.

Additional contamination mitigation steps may be necessary in adverse conditions such as strong wind, rain, flooded trench, and/or high static electricity. Such mitigation steps should be included in standard operator training.

Figure 1 shows a top-level workflow of a generic PE pipe preparation procedure² that incorporates the three critical steps above and other best-practices discussed in the final report. Figure 2 and Figure 3 show the cleaning and scraping areas schematics³ associated with the recommended best-practices procedure.

The recommended procedure given here is not a directive or a standard, nor is it intended to be complete – operators are free to accept or reject any of the steps, and/or add steps they deem necessary. The salient recommendation is that pipe preparation procedures accomplish the three steps above, by whichever means.

² This procedure is an update to the procedure presented in the final reports of this project and OTD Project 2.14.e *Guidelines/Best Practices for Scraping PE Pipe and Fittings*, and thus supersedes the earlier versions.

³ These schematics are the same as in the final reports of this project and OTD Project 2.14.e *Guidelines/Best Practices for Scraping PE Pipe and Fittings*.

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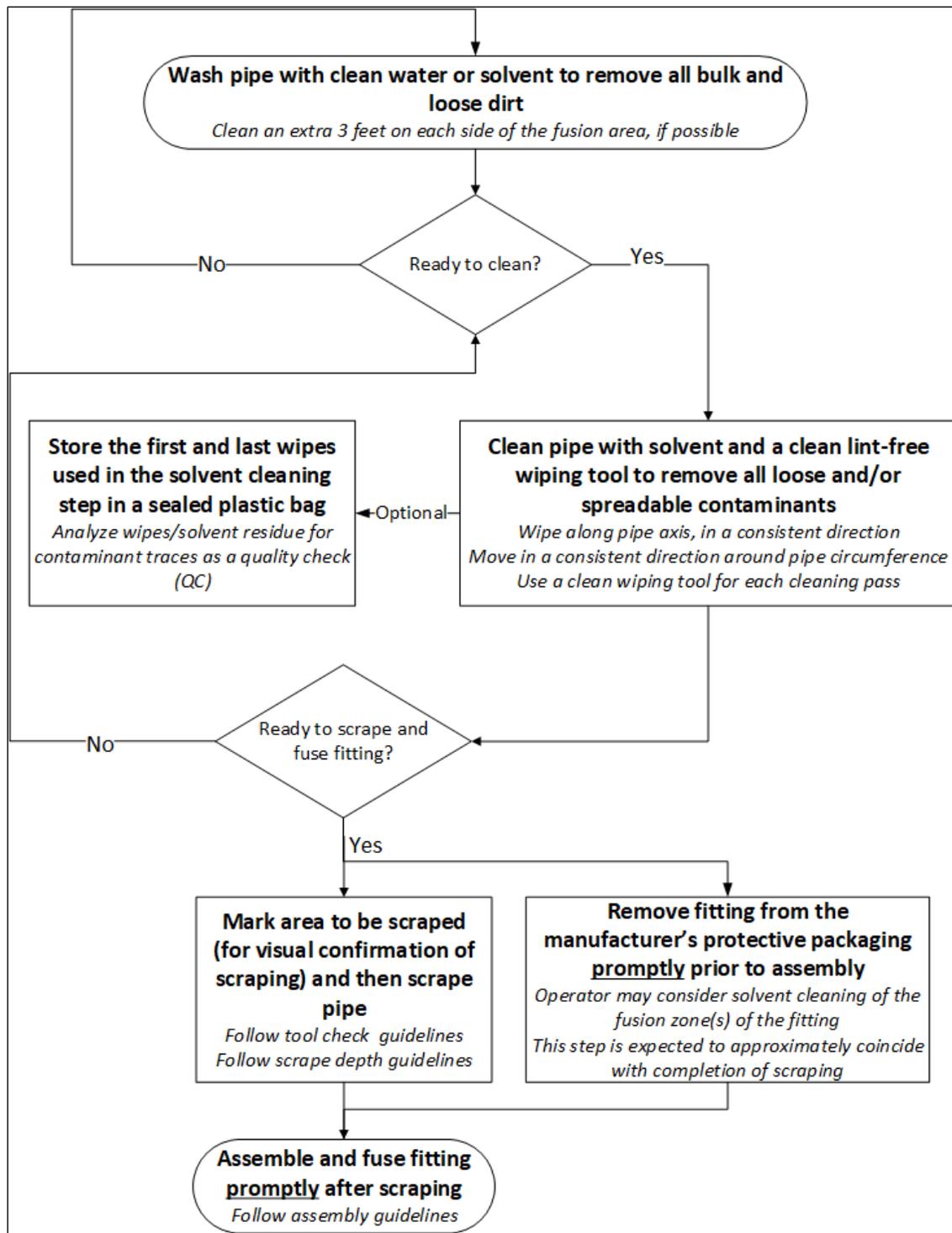


Figure 1. Top-level generic PE pipe preparation procedure incorporating best-practices

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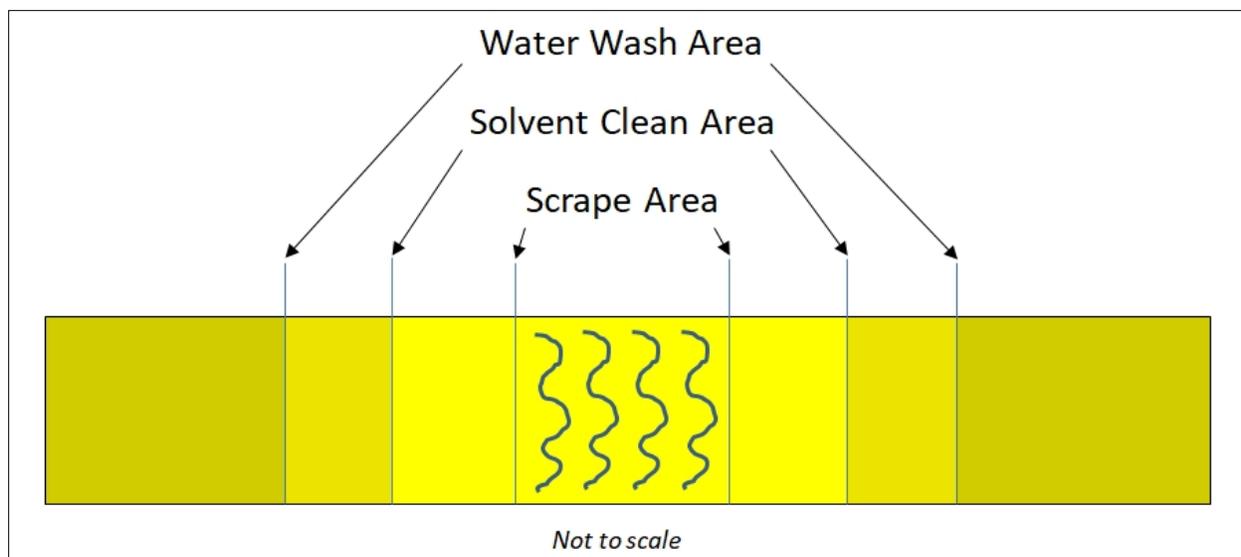


Figure 2. Schematic of cleaning and scraping areas for a saddle fitting

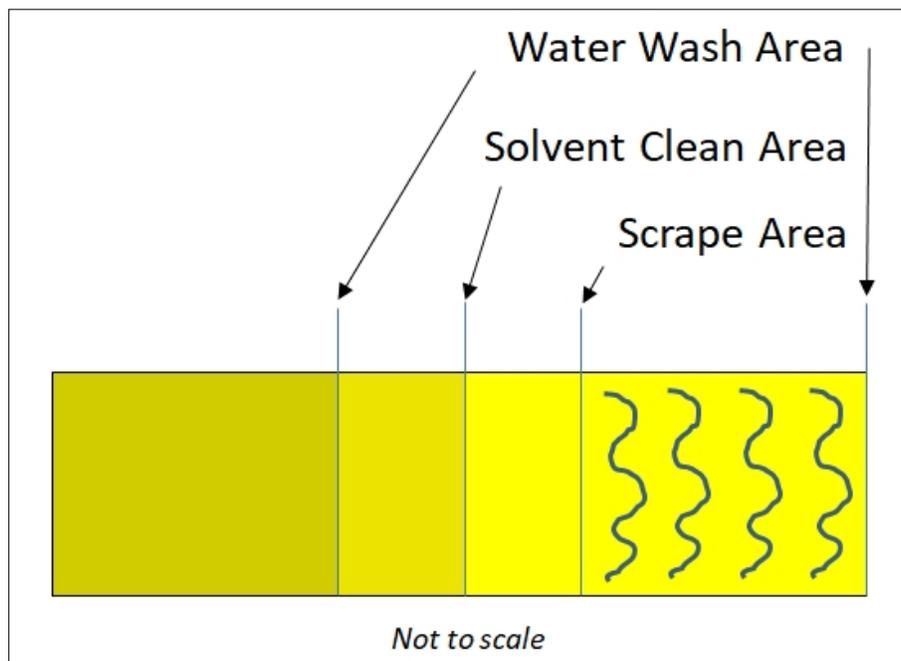


Figure 3. Schematic of cleaning and scraping areas for a coupling fitting

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General notes on PE fusion and contamination

PE fusion is a stochastic process where two molten interfaces are brought into contact such that upon cooling and solidification the interfaces co-crystallize to form a ductile welded area. This fusion process is normally robust within a relatively wide range of its critical process parameters: temperature and interfacial pressure. However, the presence of certain contaminants, such as silicates, oils, and surfactants, are highly detrimental to PE's co-crystallization process.

Fusions that fail due to contamination exhibit smooth, non-ductile separation of the fitting-pipe fusion interface, either in part or in whole. It is important to note, however, that even such areas of non-ductile bonding still have some degree of bonding which can often lead to joints that pass pressure tests (e.g., 150% MAOP) and in some cases even hold operating pressure for years, but such joints are highly sensitive to impact loads and, in cases of saddles, to forces that would cause the joint to "peel" off the pipe.

Because contamination failures are typically difficult to identify in the field, it is important that the fusion preparation processes reflect this awareness and that operators adhere to the precautions and best-practices that help minimize fusion contamination.

A note on the general applicability of this work to PE fusion

Although only electrofusion saddle fittings were tested under this scope of work, the conclusions regarding solvent cleaning and the cleaning procedure recommendations provided here are generally applicable to all PE fusion methods and fitting types. This general applicability is based on the fact that PE's fusion process is the same regardless of the method by which the surfaces to be fused are mated (see **General notes on PE fusion and contamination** above).

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Addendum Testing

The contamination removal and electrofusion test matrix covered in the final report (henceforth referred to as Test Matrix 1) included 120 test runs that covered the combinations of the contaminant/agent/tool parameters listed in **Table 1**.

Table 1. Parameters of Test Matrix 1

Contaminant	Cleaning Agent	Cleaning Tool
Talc	99% Isopropyl Alcohol	Lint-free wipe
Bentonite	91% Isopropyl Alcohol	Cloth rag
Silicon grease	Acetone	Paper towel

The cleaning procedure used in Test Matrix 1 had the following steps:

1. Scrape the pipe (using O.E.M. ‘Peeler’).
2. Contaminate the pipe.
3. Wet the tool with the solvent.
4. Make one wiping pass along pipe axis, starting at one end of the scraped zone and moving to its other end, with the wipe fully encircling the pipe (2” IPS).
5. If contaminant was still visible on the fusion zone, repeat step 3 and step 4 with a new tool.
6. Wait for pipe to dry.
7. Assemble electrofusion saddle (as soon as pipe is dry) and perform fusion.
8. Fuse saddle (at room temperature).
9. Perform decohesion test on fused saddle.

The addendum test matrices below were designed to address feedback and questions that were raised by the project sponsors during the review of the results from Test Matrix 1. Each of the four addendum matrices had a different pipe preparation procedure to address an associated question, as described below. Bolded procedure steps are deviations from the Test Matrix 1 procedure steps above.

Note that only the ‘lint-free wipe’ tool was tested to not exceed the remaining project budget. Despite testing of just a single tool, the addendum tests provided answers to the questions raised.

In tests where water was used to wash the pipe, deionized (DI) water in a squirt bottle was used.

The fused electrofusion saddles from the various addendum test matrices were subjected to an ISO 13956 Type A2 decohesion test and were ranked based on the percent of the fusion zone that exhibited ductile separation, as described in the final report.

The list of individual addendum test runs, their associated test matrix, and decohesion test ductility bin is given in **Appendix A – Addendum Test Run List with Results**. Photographs of the individual decohesion test results are provided in **Appendix B – Decohesion Test Result Photographs**.

Appendix C – Wiping Technique Reference provides a general photographic reference demonstrating the solvent cleaning wiping technique that was employed for all tests.

It is important to note that due to a limited number of test runs the results of Test Matrix 3 and Test Matrix 4, where fusion quality was inconsistent due to scraping preceding the solvent cleaning step, should be taken as instructive and not definitive.

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Test Matrix 1 – Results Reference

Provided here for quick reference are **Figure 4** and **Figure 5** which show the test results from Test Matrix 1 where the lint-free wipe was used. The results from the addendum test matrices should be compared to **Figure 4** and **Figure 5** to see how their respective test procedure modifications affected the electrofusion saddle fusion quality.

The cleaning procedure used in Test Matrix 1 had the following steps:

1. Scrape the pipe (using O.E.M. ‘Peeler’).
2. Contaminate the pipe.
3. Wet the tool with the solvent.
4. Make one wiping pass along pipe axis, starting at one end of the scraped zone and moving to its other end, with the wipe fully encircling the pipe (2” IPS).
5. If contaminant was still visible on the fusion zone, repeat step 3 and step 4 with a new tool.
6. Wait for pipe to dry.
7. Assemble electrofusion saddle (as soon as pipe is dry) and perform fusion.
8. Fuse saddle (at room temperature).
9. Perform decohesion test on fused saddle.

As can be seen in **Figure 4** and **Figure 5**, and discussed in the final report, performing solvent cleaning after scraping until contamination is visually removed, does not result in consistent removal of all surface contamination. Silicone grease is especially difficult to remove with solvent cleaning (**Figure 5**).

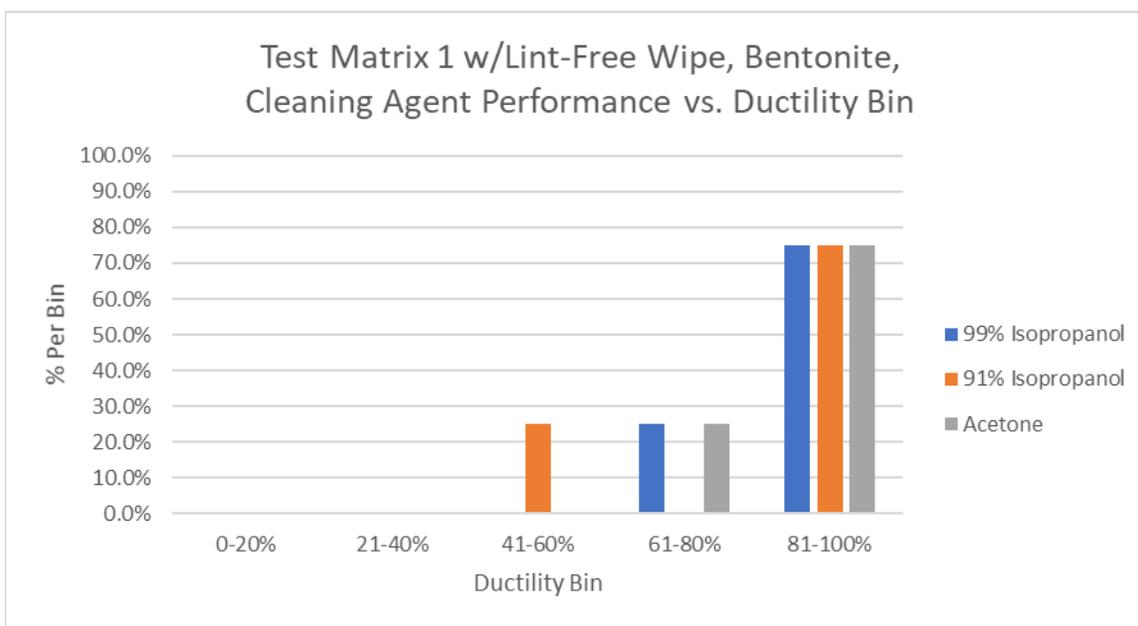


Figure 4. Test Matrix 1 results with lint-free wipe, bentonite contamination

The test results shown in **Figure 4** are from four runs per solvent.

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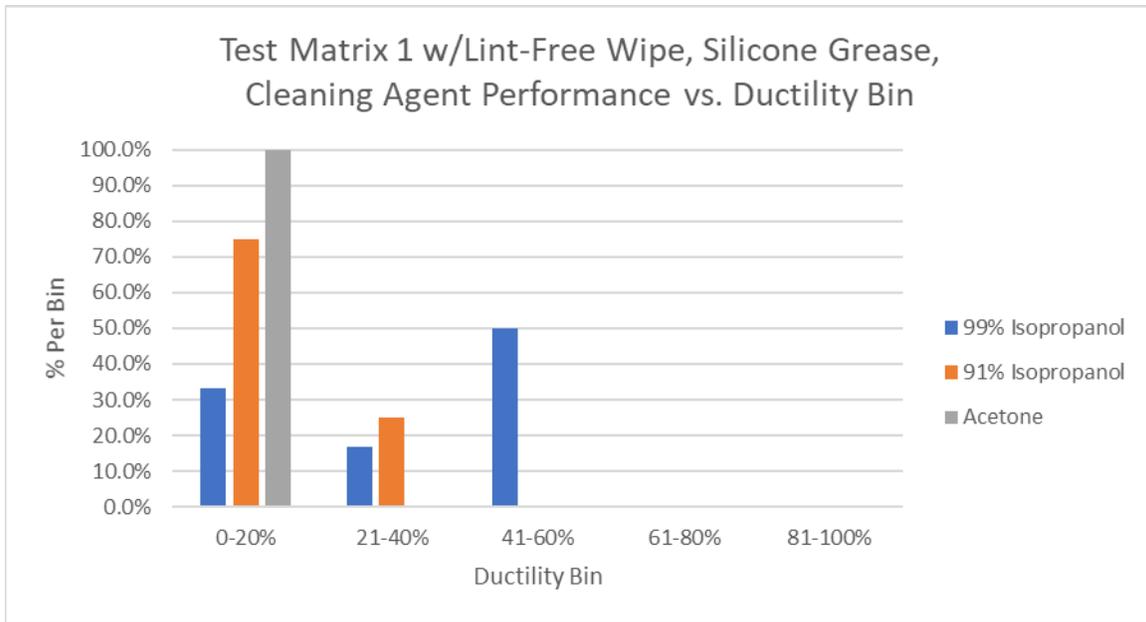


Figure 5. Test Matrix 1 results with lint-free wipe, silicone grease contamination

The test results shown in **Figure 5** are from six runs with 99% isopropyl alcohol, 4 runs with 91% isopropyl alcohol, and 4 runs with acetone.

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Test Matrix 2 – Testing the contribution of scraping to contaminant removal

This set of tests was designed to test if scraping after solvent cleaning consistently removes all contamination. The key difference between Test Matrix 2 and Test Matrix 1 is that scraping is performed after solvent cleaning.

1. Contaminate pipe (using contaminant from test matrix).
2. Saturate a new tool with agent (using agent and tool combination from test matrix).
3. Wipe (single pass) the pipe sample (entire circumference) from end to end in a single direction.
4. If contaminant is visible on the fusion zone, repeat steps 2 and 3 until it appears the contaminant has been removed.
5. **Scrape the pipe within the solvent cleaned area (using O.E.M. ‘Peeler’) once the agent on the pipe has dried.**
6. Fuse saddle (at room temperature).
7. Perform decohesion test on fused saddle.

As can be seen in **Figure 6**, performing the scraping after solvent cleaning resulted in all fusions falling in the 81-100% ductility bin, indicating consistent removal of contamination for both bentonite and silicone grease.

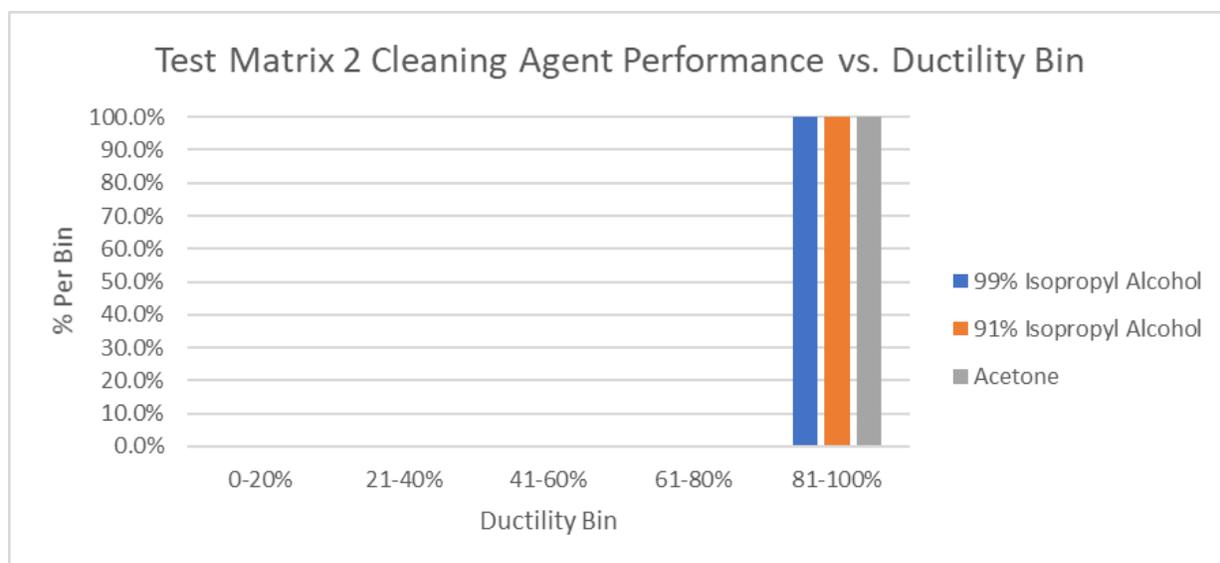


Figure 6. Test Matrix 2 results, bentonite and silicone grease

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Figure 7 shows the ductility results of the control samples, which were not contaminated. All fusions fell in the 81-100% ductility bin, as expected.

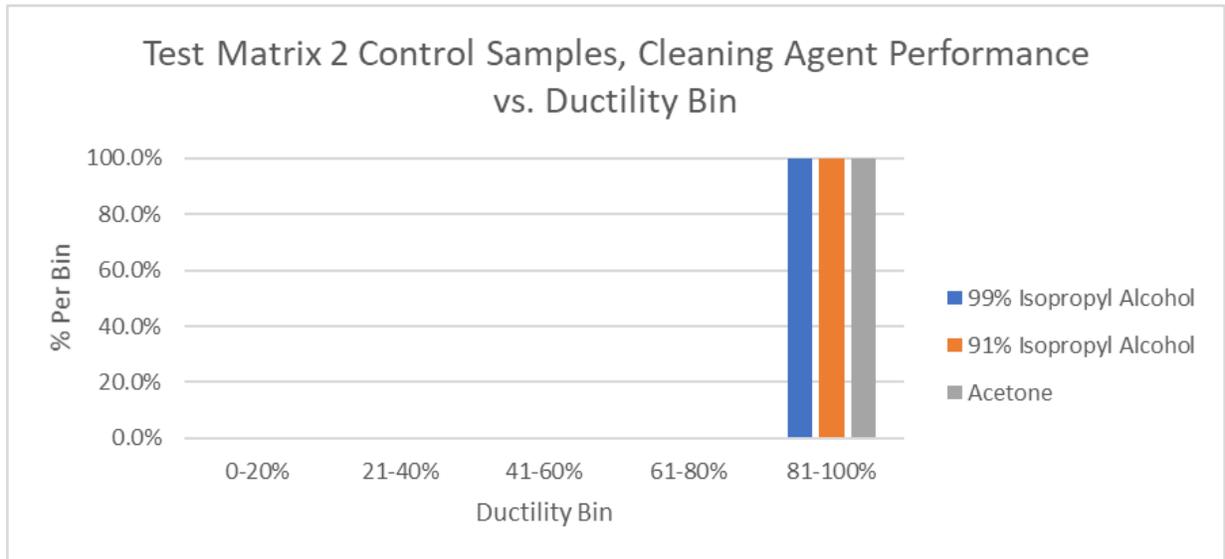


Figure 7. Test Matrix 2 control sample (no contamination) results

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Test Matrix 3 – Testing the contribution of water washing to contaminant removal

This set of tests was designed to test if water washing prior to solvent cleaning results in better surface contaminant removal than solvent cleaning alone. The key difference between Test Matrix 3 and Test Matrix 1 is that the pipe is washed with water before solvent cleaning.

1. Scrape pipe (using O.E.M. ‘Peeler’).
2. Contaminate pipe (using contaminant from test matrix).
- 3. Wash pipe with water.**
- 4. Dry water. Wipe the pipe sample (entire circumference) from end to end in a single direction (every pass with new tool).**
5. Saturate a fresh tool with agent (using agent and tool combination from test matrix).
6. Wipe (single pass) the pipe sample (entire circumference) from end to end in a single direction (within water washed area).
7. If contaminant is visible on the fusion zone, repeat steps 5 and 6 until it appears the contaminant has been removed.
8. Fuse saddle (at room temperature).
9. Perform decohesion test on fused saddle.

The results of Test Matrix 3 (**Figure 8** and **Figure 9**) show that the water wash prior to solvent cleaning had no improvement to contamination removal.

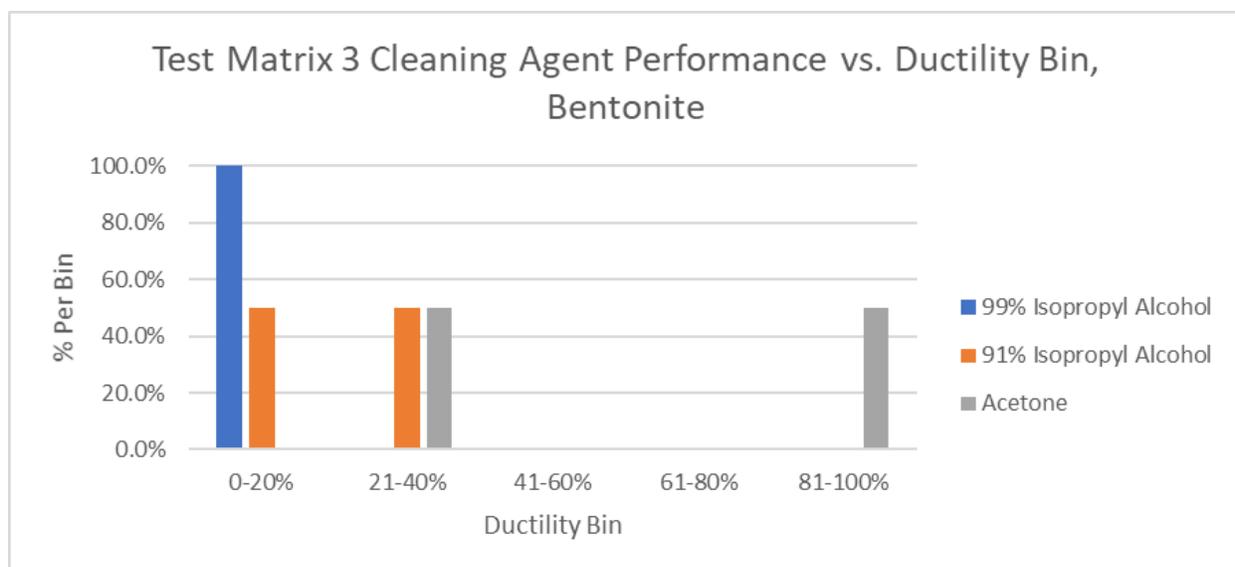


Figure 8. Test Matrix 3 results, bentonite

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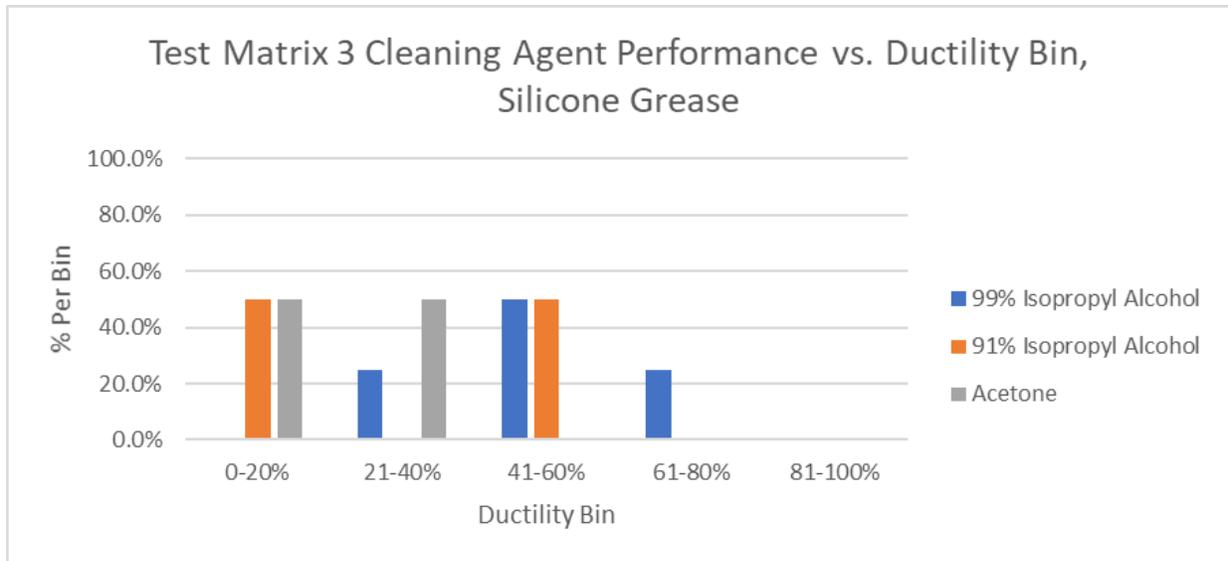


Figure 9. Test Matrix 3 results, silicone grease

Figure 10 shows the ductility results of the control samples, which were not contaminated. All fusions fell in the 81-100% ductility bin, as expected.

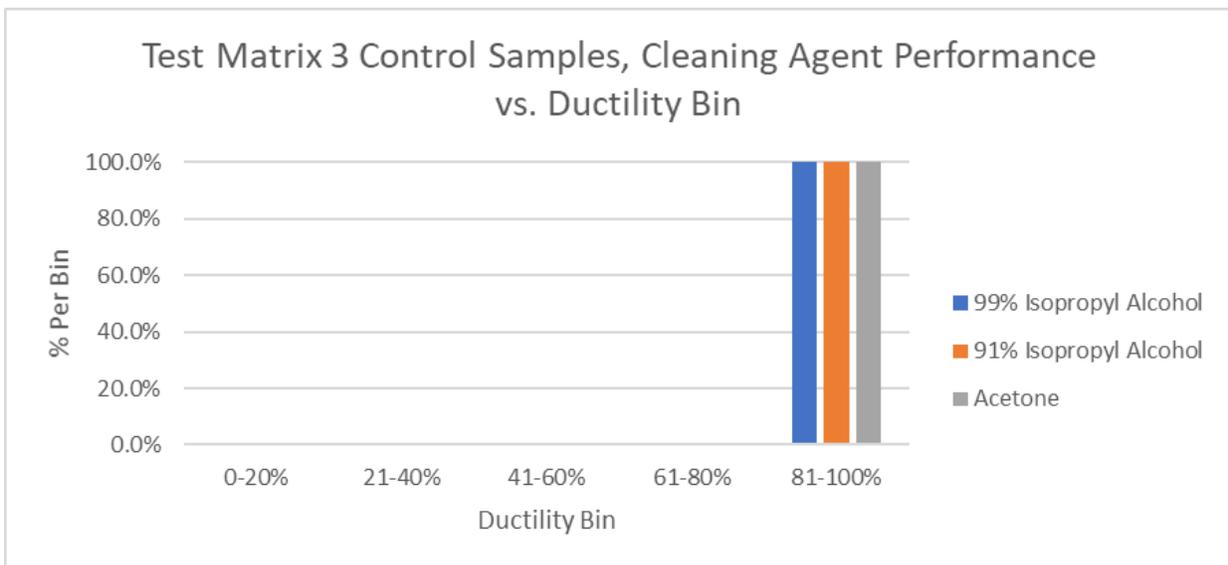


Figure 10. Test Matrix 3 control sample (no contamination) results

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Test Matrix 4 – Testing the contribution of additional solvent cleaning passes to contaminant removal

This set of tests is intended to quantify the effectiveness of additional solvent cleaning passes. These tests begin to address the question: is solvent cleaning appropriate and sufficient after scraping? This is asked in the context of contamination of pipe that has already been cleaned and scraped.

The key difference between Test Matrix 4 and Test Matrix 1 is that additional solvent wiping passes are performed after visual indication of contaminant removal.

1. Scrape pipe (using O.E.M. 'Peeler').
2. Contaminate pipe (using contaminant from test matrix).
3. Saturate a fresh tool with agent (using agent and tool combination from test matrix).
4. Wipe (single pass) the pipe sample (entire circumference) from end to end in a single direction.
5. Repeat steps 3 and 4 until it appears the contaminant has been removed.
- 6. Repeat steps 3 and 4 again based on the test matrix specification (one or two repetitions).**
7. Fuse saddle (at room temperature).
8. Perform decohesion test on fused saddle.

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The results of Test Matrix 4 show that repeated solvent wiping passes improved bentonite removal with both 99% isopropyl alcohol and acetone (**Figure 11**).

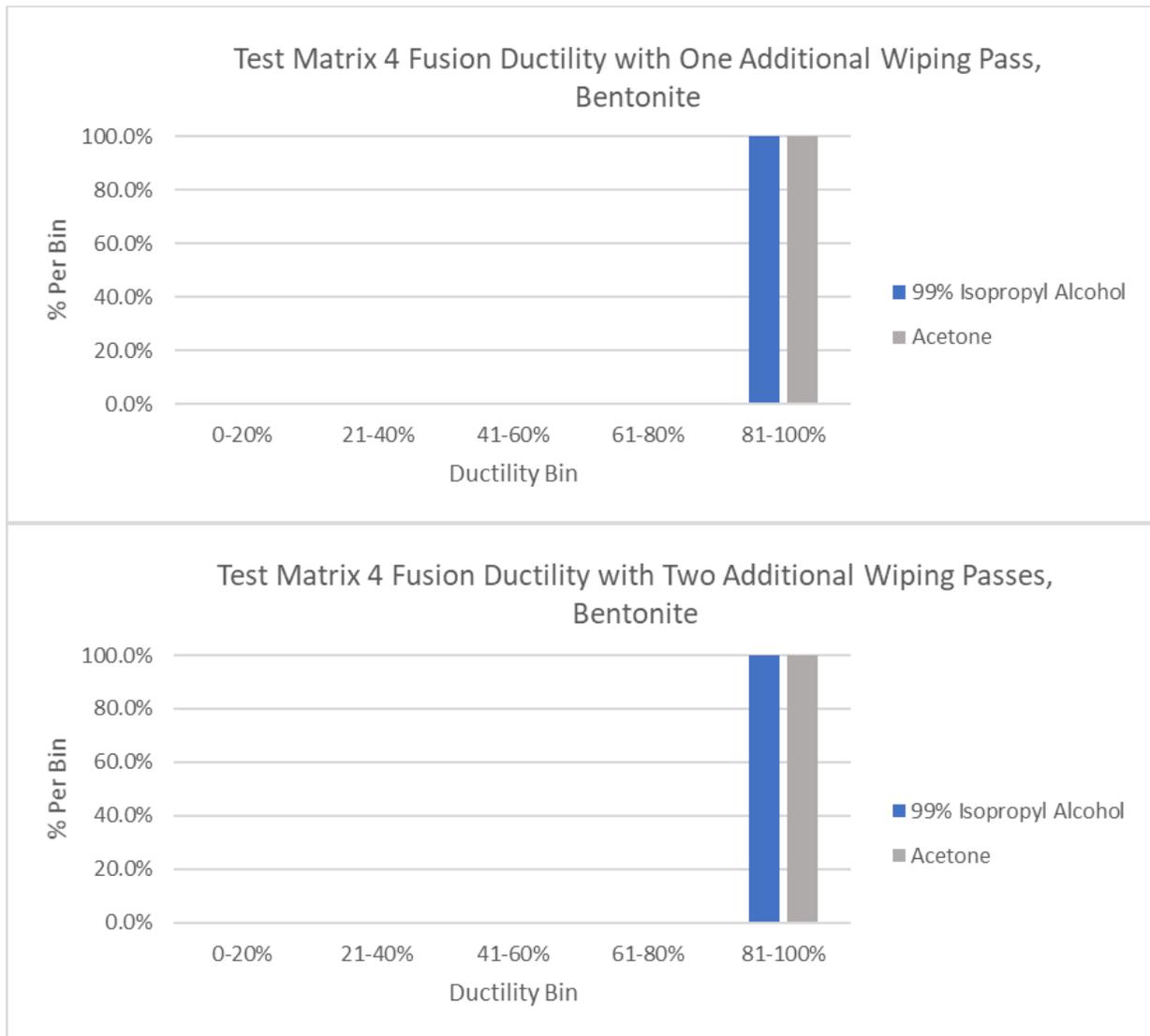


Figure 11. Test Matrix 4 results, bentonite

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Additional wiping passes also improved silicone grease removal with 99% isopropyl alcohol, but did not appear to improve removal with acetone (Figure 12). It should be noted that only four runs with acetone were performed under this matrix and therefore these results should not be treated as definitive.

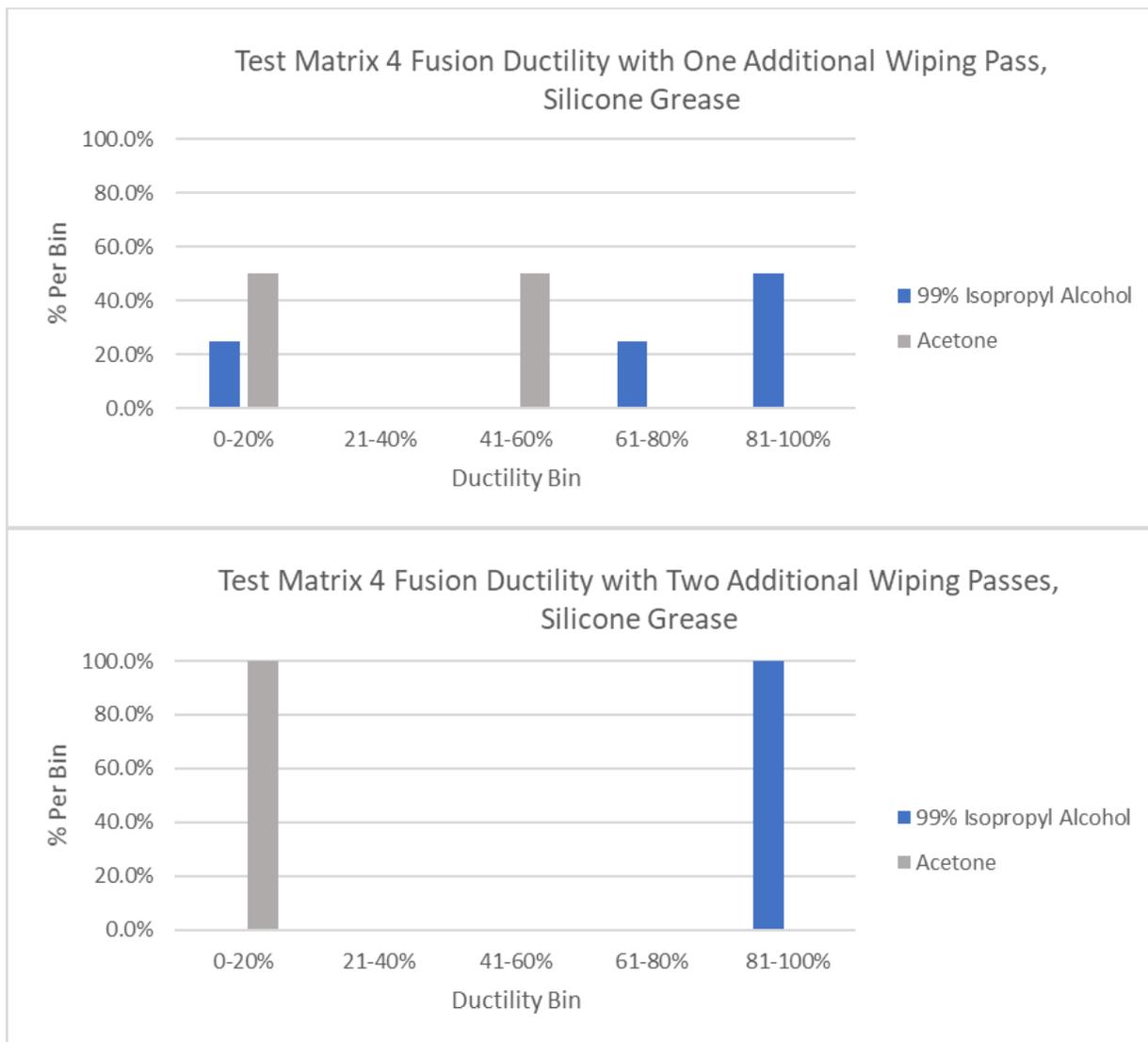


Figure 12. Test Matrix 4 results, silicone grease

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Figure 13 shows the ductility results of the control samples, which were not contaminated. All fusions fell in the 81-100% ductility bin, as expected.



Figure 13. Test Matrix 4 control sample (no contamination) results

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Test Matrix 5 – Testing of proposed best practices procedure

This set of tests is designed to determine if the preparation procedure based on the lessons learned in this project and OTD Project 21674 *Scraping Best Practices* consistently results in 100% ductile fusions.

The key difference between Test Matrix 5 and Test Matrix 1 is that the pipe is washed with water before solvent cleaning, and scraping is performed after solvent cleaning.

1. Contaminate pipe (using contaminant from test matrix).
2. **Wash pipe with water.**
3. **Dry water. Wipe the pipe sample (entire circumference) from end to end in a single direction (every pass with new tool).**
4. Saturate a fresh tool with agent (using agent and tool combination from test matrix).
5. Wipe (single pass) the pipe sample (entire circumference) from end to end in a single direction.
6. Repeat steps 4 and 5 until it appears the contaminant has been removed.
7. **Scrape the pipe within the solvent cleaned area (O.E.M. 'Peeler') once the agent on the pipe has dried.**
8. Fuse saddle (at room temperature).
9. Perform decohesion test on fused saddle.

Test Matrix 5 has the same results (**Figure 14**) as Test Matrix 2 (**Figure 6**). All fusions fell within the top ductility band, confirming that the proposed best-practices procedure in the final report can consistently remove surface contaminants, with all tested contaminants and solvents.

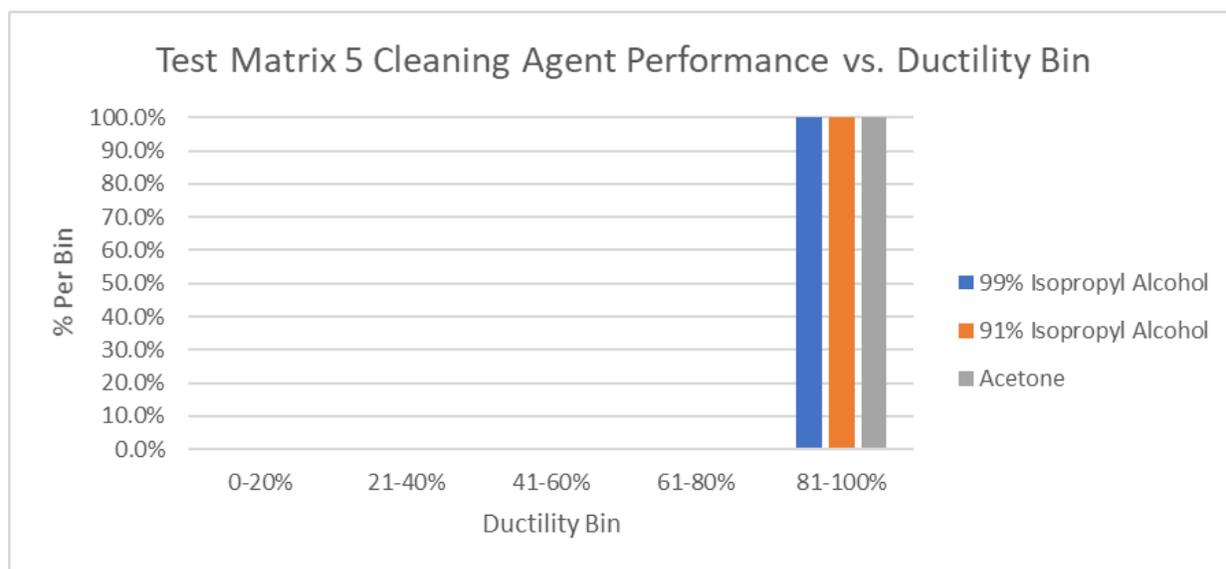


Figure 14. Test Matrix 5 results, bentonite and silicone grease

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Figure 15 shows the ductility results of the control samples, which were not contaminated. All fusions fell in the 81-100% ductility bin, as expected.

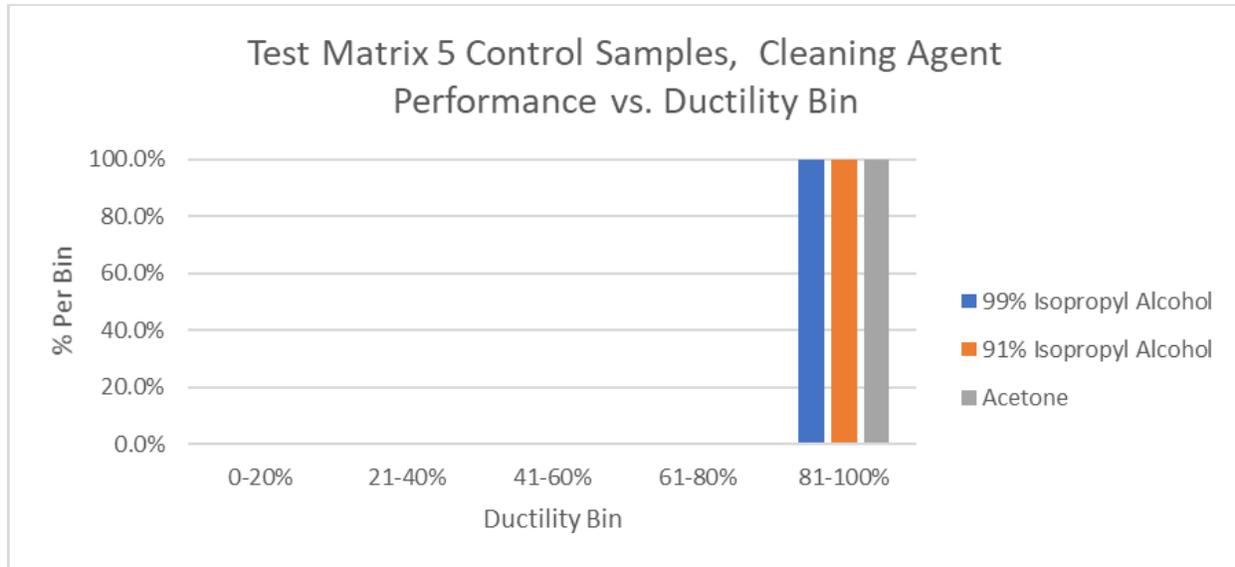


Figure 15. Test Matrix 5 control sample (no contamination) results

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Of special mention was one test run – Index 86 in Table 2, in **Appendix A – Addendum Test Run List** – where the scraping left a non-scraped sliver, as can be seen in **Figure 16**. This example of incomplete scraping, where only the missed sliver had no ductile bonding, reinforces two of the major takeaways from the final report and this addendum (further discussed in **Discussion and Conclusions**):

- Removal of loose contaminants is crucial for preventing the transfer of contaminants as scraping is performed, and,
- Scraping is the critical step for removal of any remaining, non-loose, surface contaminants.

Additionally, this example illustrates the importance of operator training on the tools they use and procedural checks of workmanship in the field.

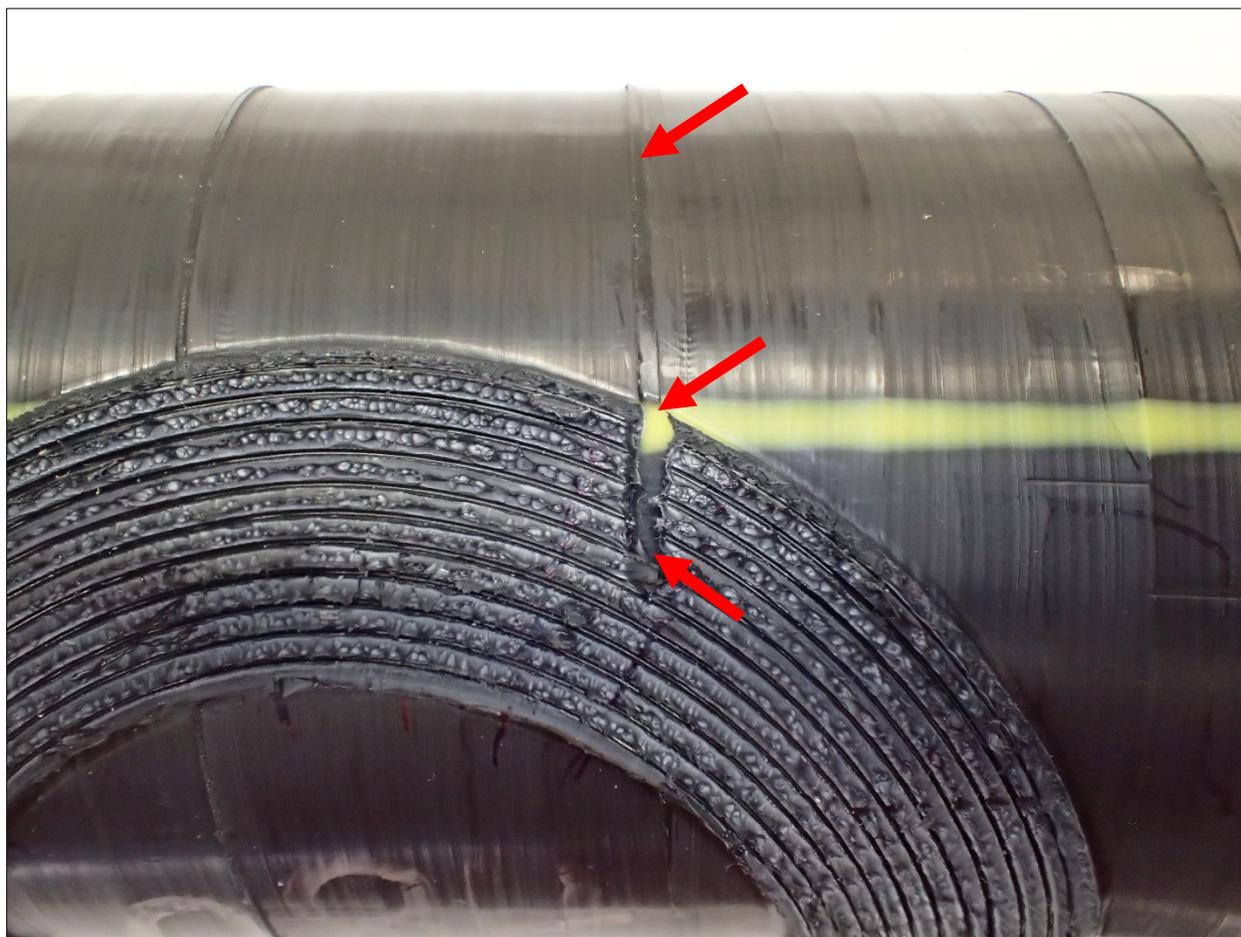


Figure 16. Example of incomplete scraping

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Test Matrix 6 – Testing of proposed best practices procedure without solvent cleaning

This set of tests is designed to assess if solvent cleaning is critical in achieving good fusions. The procedure is the same as Test Matrix 5 except for omitting the solvent cleaning step and using water as the cleaning agent. Also, silicone grease and bentonite powder were applied simultaneously to contaminate the pipe, as shown in **Figure 18** through **Figure 20**.

1. Contaminate pipe with silicone grease (three longitudinal lines over the fusion zone) and bentonite powder.
2. Wash pipe with water.
3. Dry water. Wipe the pipe sample (entire circumference) from end to end in a single direction (every pass with new tool).
4. Repeat steps 2 and 3 until it appears the contaminant(s) has been removed.
5. Scrape pipe within the water washed area (O.E.M. 'Peeler') once the water on the pipe has dried.
6. Fuse saddle (at room temperature).
7. Perform decohesion test on fused saddle.

All the fusions from Test Matrix 6 fell within the top ductility band (**Figure 17**), indicating that cleaning with a solvent (or choice of solvent) is not critical. This finding lends support to the understanding that what is critical is that any loose contaminants are thoroughly removed prior to scraping, which is achievable with water⁴. The scraping step is the critical step where non-loose surface contaminants are removed.

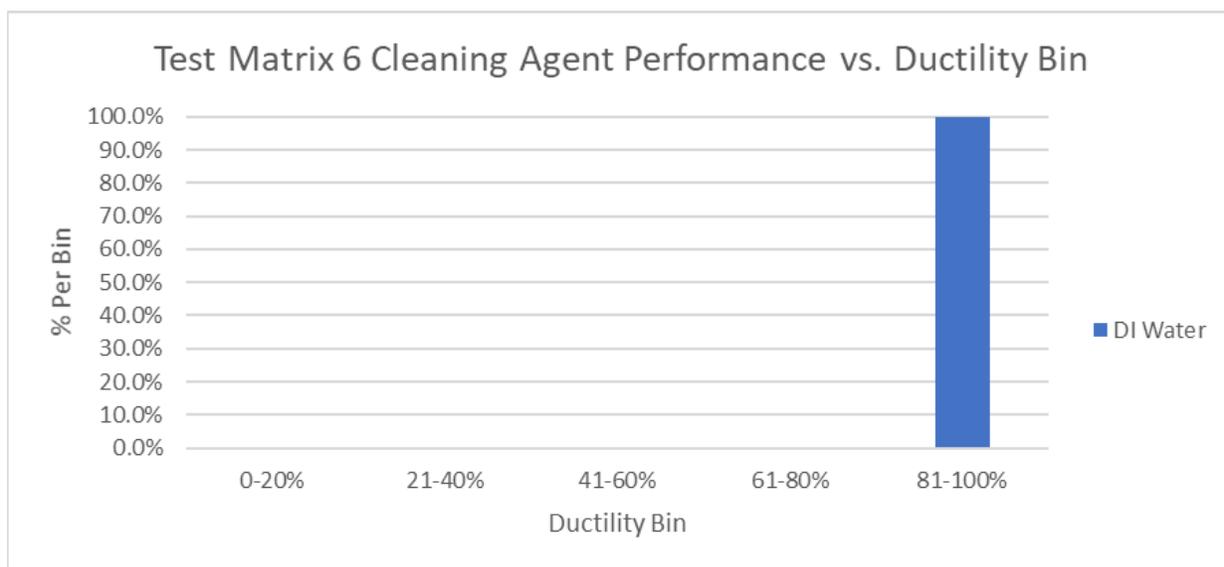


Figure 17. Test Matrix 6 results, bentonite and silicone grease

⁴ Water is not appropriate at temperatures at or below its freezing point. Solvent cleaning is necessary under these conditions. Solvents are also generally preferable from an evaporation perspective.

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Figure 18. Test Matrix 6 specimen after silicone grease contamination, red arrows point to the three lines

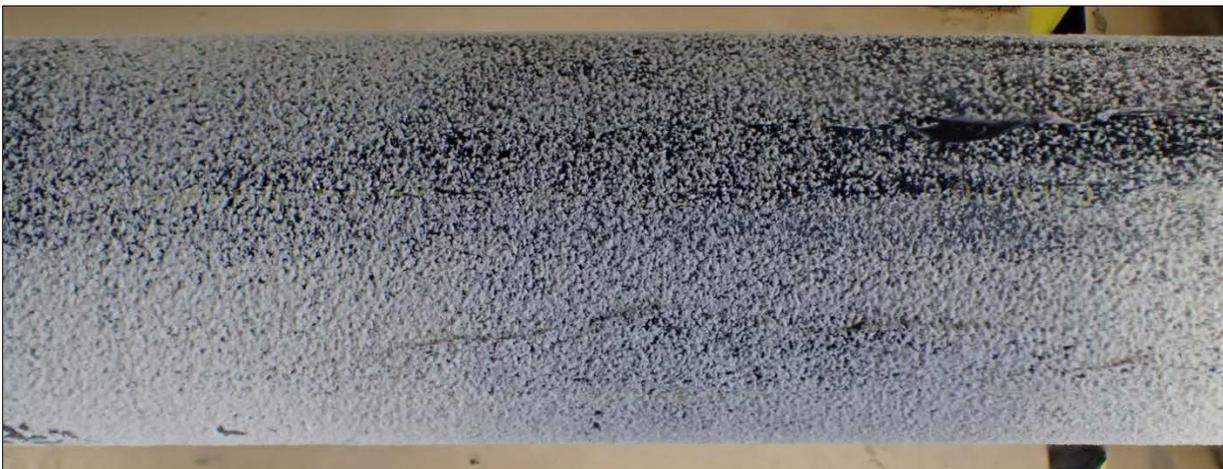


Figure 19. Test Matrix 6 specimen after bentonite powder contamination



Figure 20. Test Matrix 6 specimen after water wash and wipe. Red arrows show remaining silicone grease streaks.

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Test Matrix 7 – Testing the influence of solvent cleaning after scraping on fusion ductility

This set of tests is designed to determine if solvent cleaning is detrimental to PE fusion. The key difference between the recommended best practices procedure and this test procedure is the additional solvent wiping pass after scraping. This procedure will include both contaminated and non-contaminated pipes.

The preparation procedure will be as follows:

1. Contaminate pipe (if applicable according to test matrix)
2. Saturate a fresh tool with agent (using agent from Test Matrix 7).
3. Wipe (single pass) the pipe sample (entire circumference) from end to end in a single direction.
4. Repeat steps 1 and 2 until it appears the pipe is clean.
5. Scrape pipe (O.E.M. 'Peeler') once the agent on the pipe has dried.
6. **Saturate a fresh tool with agent (using agent from Test Matrix 7).**
7. **Wipe (single pass) the pipe sample (entire circumference) within the scraped area in a single direction.**
8. Fuse saddle (at room temperature), once the agent on the pipe has dried.
9. Perform decohesion test on fused saddle.

The results of Test Matrix 7, shown in **Figure 21** and **Figure 22**, indicate that additional solvent cleaning passes after scraping are not inherently detrimental to PE fusion, however, it is important to note that care should be taken to avoid the possibility of transferring contaminants onto the scraped surface via the solvent cleaning process, for example: by wiping beyond the scraped area or exposing the wipe to a dusty environment. Sealed, pre-saturated solvent wipes can help minimize exposure to a dusty environment.

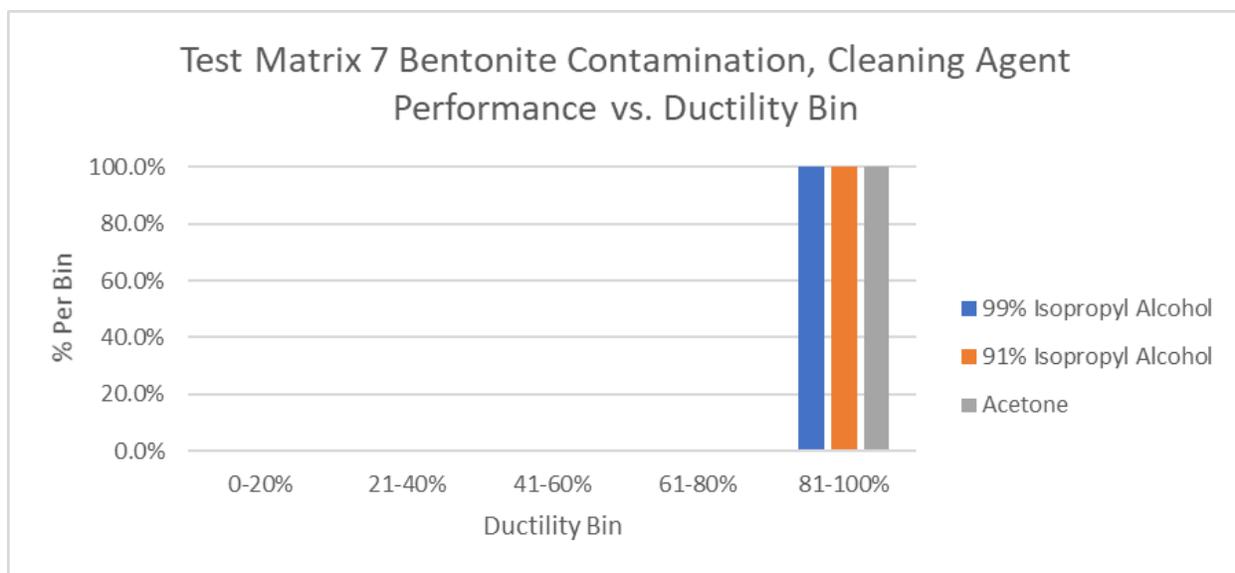


Figure 21. Test Matrix 7 results, samples with bentonite contamination

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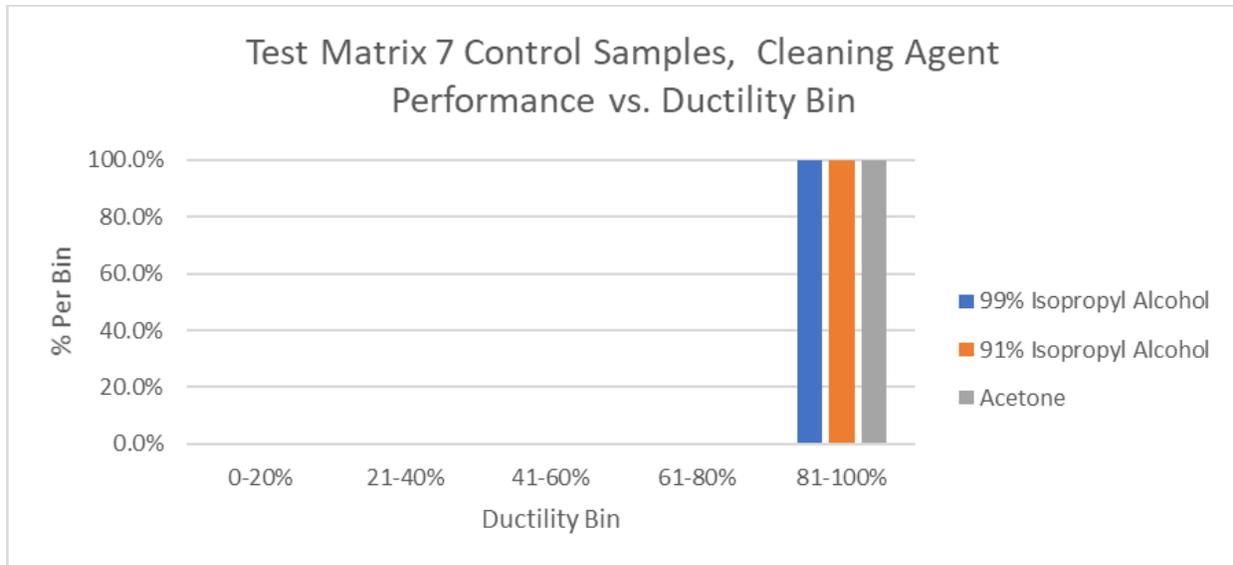


Figure 22. Test Matrix 7 control sample (no contamination) results

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Comparison of Solvent Performance

Figure 23 shows a comparison between fusions prepared with different solvents, where scraping was followed by contamination, followed by solvent cleaning. The chart shows what is the probability of a fusion (performed under these conditions) to fall within each ductility bin. The error bars represent the upper and lower credibility bounds of the respective probabilities.

As can be seen in **Figure 23**, fusions that followed solvent cleaning with 99% isopropyl alcohol were more likely to fall within the top ductility bin than 91% isopropyl alcohol. Solvent cleaning with acetone was less likely to produce a fusion in the top ductility bin than both 99% and 91% isopropyl alcohol. Overall, however, when contamination and solvent cleaning follow scraping, all solvents showed the same probability trends with less than a 50% chance of a successful fusion. These probabilities were obtained from 62 99% isopropyl alcohol runs, 48 91% isopropyl alcohol runs, and 48 acetone runs (Test Matrix 1, 3, and 4).

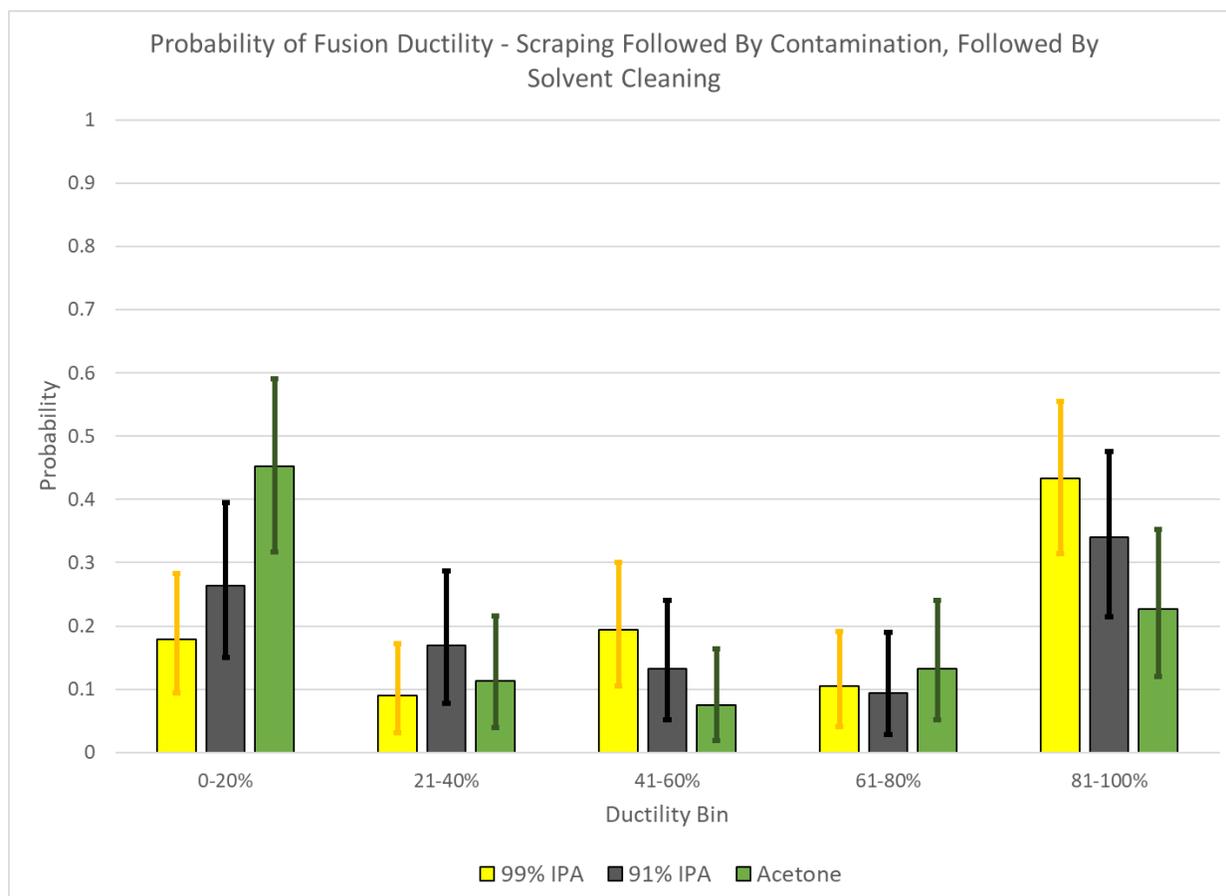


Figure 23. Solvent performance comparison, probability of fusion ductility – scraping followed by contamination, followed by solvent cleaning

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Figure 24 shows a comparison between fusions prepared with different solvents (as in **Figure 23**), but for fusions where scraping followed contamination and solvent cleaning. The results for fusions performed on pipes that were prepared with different solvents are the same in this case; showing a high probability of a successful fusion, due to scraping being the final preparation step before fusion. These probabilities were obtained from 20 99% isopropyl alcohol runs, eight 91% isopropyl alcohol runs, and 16 acetone runs (Test Matrix 2, 5, and 6).

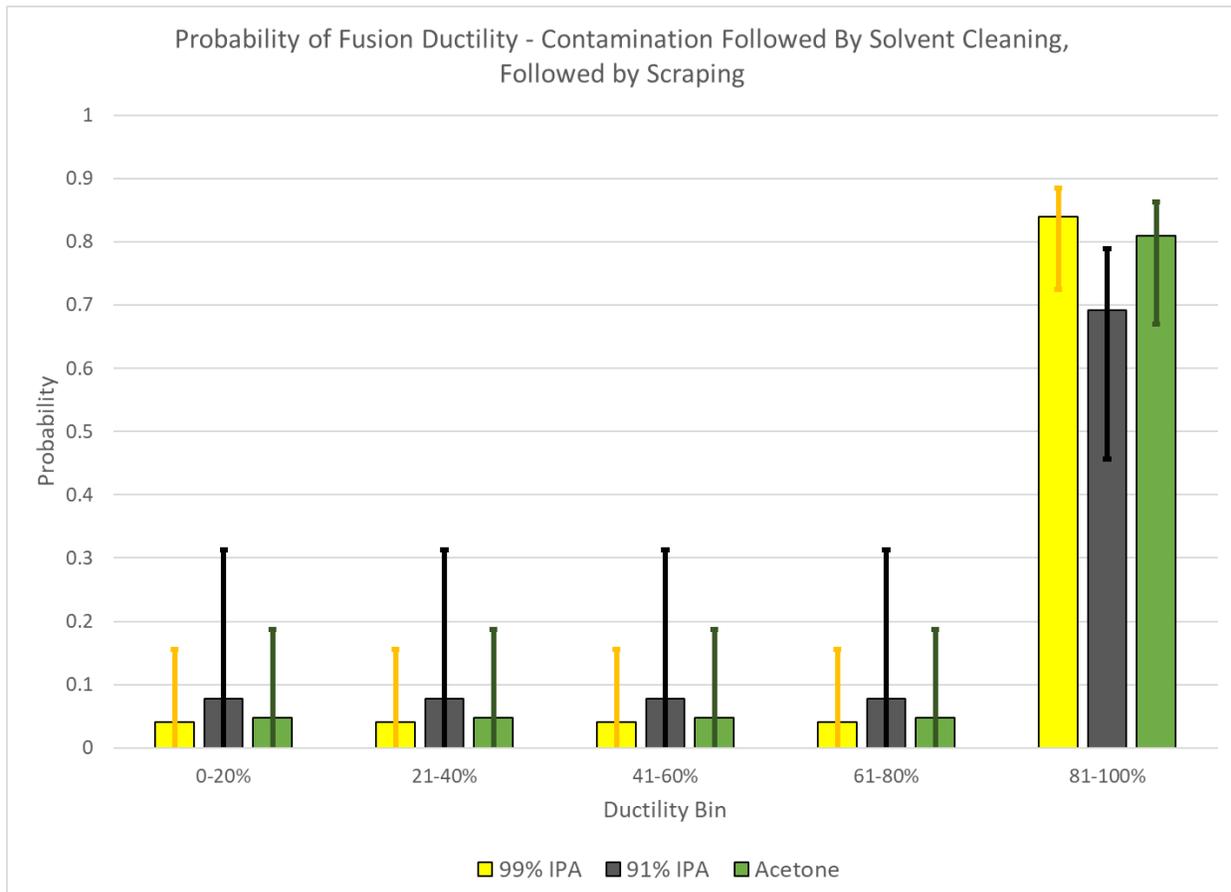


Figure 24. Solvent performance comparison, probability of fusion ductility – contamination followed by solvent cleaning, followed by scraping

In conclusion, based on the tests performed, comparison between solvents shows that:

- All solvents have less than a 50% likelihood of removing all contaminants, and,
- When scraping was performed after solvent cleaning, all fusions fell in the top ductility bin.

Thus, solvent choice is not critical – scraping is the critical final step for contamination removal.

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Comparison of Fusions Performed on MDPE Pipe and HDPE Pipe

Figure 25 shows a comparison between the fusions performed on MDPE pipe and HDPE pipe, where scraping was followed by contamination, followed by solvent cleaning. The chart shows what is the probability of a fusion (performed under these conditions) to fall within each ductility bin. The error bars represent the upper and lower credibility bounds of the respective probabilities.

As can be seen in **Figure 25**, fusions performed on HDPE pipe exhibited a higher probability that the ductility will fall in the desired 81-100% bin, as compared to fusions performed on MDPE pipe. It should be noted here that all electrofusion saddle fittings were made from HDPE and, therefore, this result is likely reflecting a difference between HDPE-to-HDPE and HDPE-to-MDPE fusions when contamination is present.

Overall, however, when contamination and solvent cleaning follow scraping, the fusion to HDPE and MDPE pipes showed the same probability trends with less than a 50% chance of a successful fusion. These probabilities were obtained from 79 fusions per pipe material (Test Matrix 1, 3, and 4).

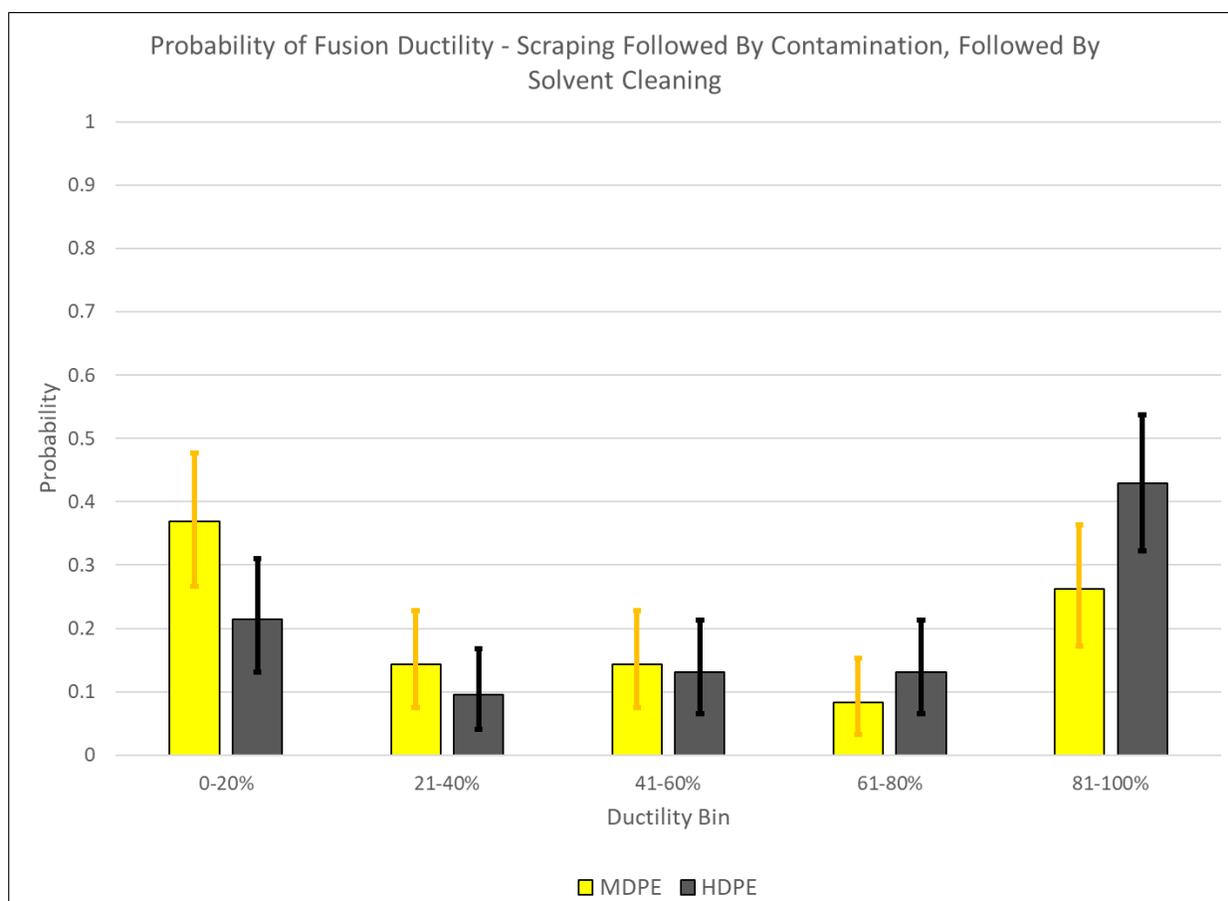


Figure 25. HDPE-to-MDPE vs HDPE-to-HDPE fusions, probability of fusion ductility – scraping followed by contamination, followed by solvent cleaning

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Figure 26 shows a comparison between fusions performed on MDPE pipe and HDPE pipe (as in **Figure 25**), but for fusions where scraping followed contamination and solvent cleaning. The results for fusions performed on HDPE and MDPE pipes are the same in this case; showing a high probability of a successful fusion. These probabilities were obtained from 24 fusions per pipe material (Test Matrix 2, 5, and 6).

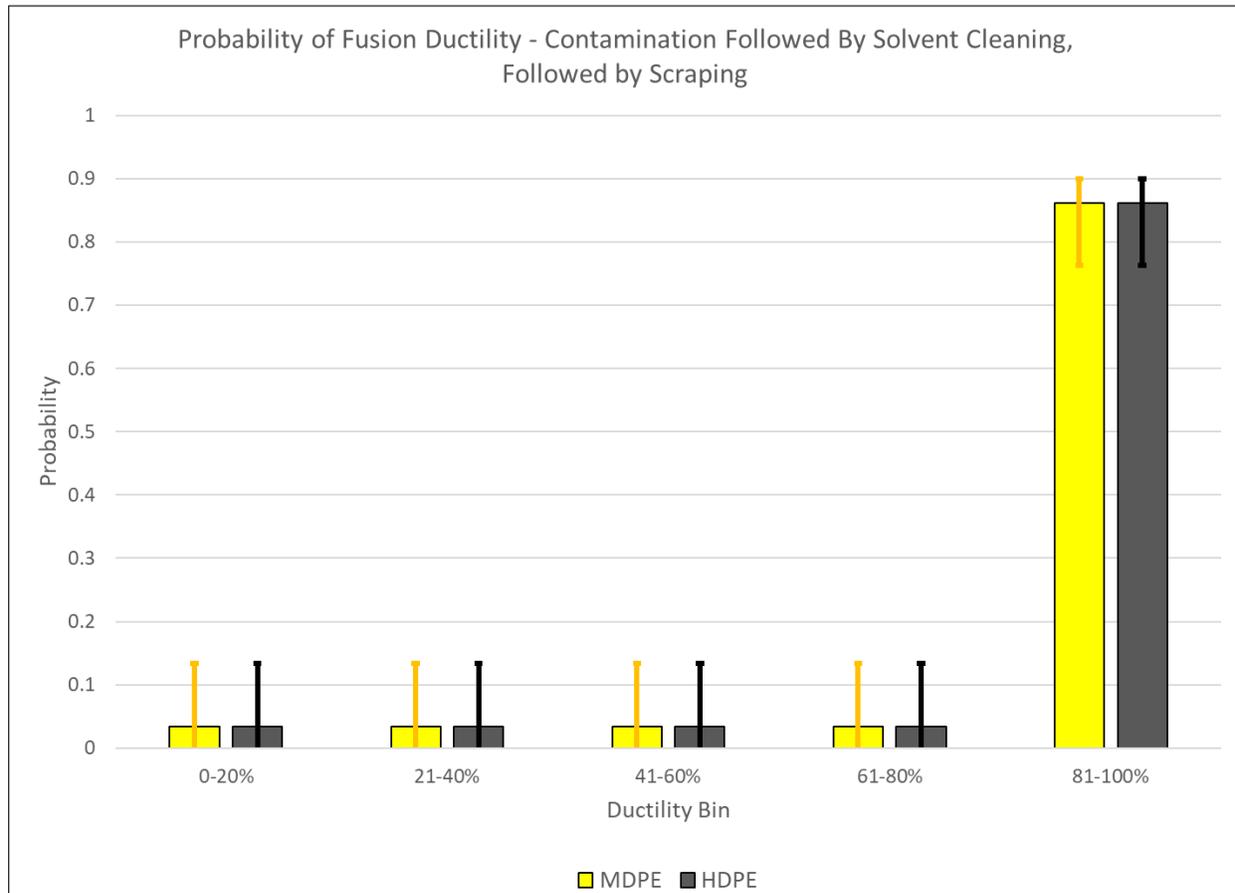


Figure 26. HDPE-to-MDPE vs HDPE-to-HDPE fusions, probability of fusion ductility – contamination followed by solvent cleaning, followed by scraping

In conclusion, comparison between HDPE-to-HDPE and HDPE-to-MDPE fusions shows that:

1. Both material combinations are similarly affected by contamination with less than a 50% chance of a successful fusion when contamination is present.
2. The suggested best practice of scraping promptly before fitting assembly and fusion applies to both material combinations.

The conclusions above should extend to MDPE-to-MDPE fusions as well.

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Discussion and Conclusions

The addendum test results have led to the following key observations:

1. Tests where scraping was performed after contamination and water washing and/or solvent cleaning resulted in ductile bonding.
2. In tests where scraping was performed before contamination, additional solvent cleaning wipes improved removal of contamination, but did not always remove all contamination.
3. Test results where additional solvent cleaning was performed after scraping indicate that solvent cleaning is not inherently detrimental to PE fusion.

Observation 1 directly supports the recommended best practices scraping procedure provided in the final report, where scraping is performed after cleaning (removal of loose surface contaminants) and fitting assembly and fusion are performed promptly after scraping to minimize the chances of contamination of the scraped pipe.

Observation 1 also suggests that the choice of cleaning solvent for a surface that is going to be scraped is not critical if scraping is performed promptly prior to fusion. This is further supported by the results of Test Matrix 6 where only a water wash was performed (no solvent cleaning) to remove the loose bentonite powder and bulk of silicone grease.

Observation 2 reinforces the observations and conclusions in the final report where solvent cleaning was found to be inconsistent in terms of surface contamination removal. Observation 2, however, also suggest that multiple solvent wiping passes may be a valid option when scraped pipe has been contaminated. Further work on solvent cleaning technique and multiple wiping passes would be required to prove this, as the number of test runs under this scope was limited.

Observation 3 indicates that the practice of solvent cleaning of fusion surfaces between the scraping and fusion steps is not inherently detrimental to PE fusion. However, Observation 1 also indicates that this practice is not essential. It is up to the operator to determine if this practice should be included in their fusion procedures. It is important to note that care should be taken to avoid the possibility of transferring contaminants onto the scraped surface via the solvent cleaning process, for example: by wiping beyond the scraped area or exposing the wipe to a dusty environment. Also, if a rough surface has been created by the scraping process, there is a possibility that the wiping tool may get snagged and leave some of its matter (fibers) on the pipe. Sealed, pre-saturated solvent wipes can help minimize exposure to a dusty environment.

Also of note is that if scraping tools with serrated blades are used, then solvent cleaning of the roughened pipe surface cannot guarantee that contamination will be removed from in between the ridges of the scraped surface.

It should be noted that in all the addendum tests, the electrofusion saddles were taken out from their individual packaging promptly prior to assembly and no cleaning was performed on them. If a fitting becomes contaminated in the field, it should be treated in the same manner as a scraped pipe that becomes contaminated – that is, with acknowledgment that solvent cleaning may not fully remove the types of contaminants tested in this work (talc, bentonite, silicone grease) and thus rejection of the fitting should be considered. Talc and bentonite may be considered as proxies for other types of mineral silicates (soil dirt) in terms of their detrimental effect on PE fusion.

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Potential Future Work

Additional wiping tool and solvent combinations, as well as the associated wiping techniques, could be tested in a follow-on project. This work will be applicable to cases where solvent cleaning is performed after scraping.

Future work could also include testing of non-rotary, hand-held scrapers, which may be the only available scraping tool for saddle installations on large diameter pipes (10" IPS and above).

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Appendix A – Addendum Test Run List with Results

Table 2. Addendum Test Matrices Run List and Decohesion Test Ductility Bin

Matrix Index	Run Index	Contaminant	Cleaning Agent	Cleaning Tool	Pipe Material	Replicate Index	Additional Passes	Decohesion Ductility Bin
2	1	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	2	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
2	3	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	4	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
2	5	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	6	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
2	7	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	8	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
2	9	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	10	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	11	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	12	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	13	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
2	14	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
2	15	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
2	16	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
2	17	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	18	None	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	19	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
2	20	None	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
2	21	None	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
2	22	None	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
3	23	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	0-20%

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3	24	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	0-20%
3	25	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	0-20%
3	26	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	0-20%
3	27	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	41-60%
3	28	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	21-40%
3	29	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	41-60%
3	30	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	61-80%
3	31	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	21-40%
3	32	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	0-20%
3	33	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	0-20%
3	34	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	41-60%
3	35	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	0	21-40%
3	36	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
3	37	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	1	0	0-20%
3	38	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	1	0	21-40%
3	39	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
3	40	None	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
3	41	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
3	42	None	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
3	43	None	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
3	44	None	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
4	45	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	81-100%
4	46	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	1	81-100%
4	47	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	1	81-100%
4	48	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	1	81-100%
4	49	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	81-100%
4	50	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	2	81-100%
4	51	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	2	81-100%

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4	52	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	2	81-100%
4	53	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	61-80%
4	54	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	1	0-20%
4	55	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	1	81-100%
4	56	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	1	81-100%
4	57	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	81-100%
4	58	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	2	81-100%
4	59	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	2	81-100%
4	60	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	2	81-100%
4	61	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	81-100%
4	62	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	1	81-100%
4	63	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	81-100%
4	64	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	2	81-100%
4	65	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	41-60%
4	66	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	1	21-40%
4	67	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	21-40%
4	68	Silicone Grease	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	2	61-80%
4	69	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	1	81-100%
4	70	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	1	81-100%
4	71	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	2	81-100%
4	72	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	2	81-100%
4	73	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	1	1	0-20%
4	74	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	1	1	41-60%
4	75	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	1	2	0-20%
4	76	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	1	2	0-20%
4	77	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	81-100%
4	78	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	81-100%
4	79	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	1	81-100%

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4	80	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	2	81-100%
4	81	None	Acetone	Lint-Free Wipe	MDPE	1	1	81-100%
4	82	None	Acetone	Lint-Free Wipe	MDPE	1	2	81-100%
5	83	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
5	84	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
5	85	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
5	86	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
5	87	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
5	88	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
5	89	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
5	90	Silicone Grease	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
5	91	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
5	92	Bentonite	Acetone	Lint-Free Wipe	MDPE	2	0	81-100%
5	93	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
5	94	Bentonite	Acetone	Lint-Free Wipe	HDPE	2	0	81-100%
5	95	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
5	96	Silicone Grease	Acetone	Lint-Free Wipe	MDPE	2	0	81-100%
5	97	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
5	98	Silicone Grease	Acetone	Lint-Free Wipe	HDPE	2	0	81-100%
5	99	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
5	100	None	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
5	101	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
5	102	None	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
5	103	None	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
5	104	None	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
6	105	Silicone Grease & Bentonite	DI Water	Lint-Free Wipe	MDPE	1	0	81-100%
6	106	Silicone Grease & Bentonite	DI Water	Lint-Free Wipe	MDPE	2	0	81-100%

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6	107	Silicone Grease & Bentonite	DI Water	Lint-Free Wipe	HDPE	1	0	81-100%
6	108	Silicone Grease & Bentonite	DI Water	Lint-Free Wipe	HDPE	2	0	81-100%
7	109	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
7	110	None	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
7	111	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
7	112	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
7	113	None	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
7	114	None	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
7	115	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
7	116	Bentonite	99% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
7	117	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
7	118	None	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
7	119	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	1	0	81-100%
7	120	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	MDPE	2	0	81-100%
7	121	None	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
7	122	None	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
7	123	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	1	0	81-100%
7	124	Bentonite	91% Isopropyl Alcohol	Lint-Free Wipe	HDPE	2	0	81-100%
7	125	None	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
7	126	None	Acetone	Lint-Free Wipe	MDPE	2	0	81-100%
7	127	Bentonite	Acetone	Lint-Free Wipe	MDPE	1	0	81-100%
7	128	Bentonite	Acetone	Lint-Free Wipe	MDPE	2	0	81-100%
7	129	None	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
7	130	None	Acetone	Lint-Free Wipe	HDPE	2	0	81-100%
7	131	Bentonite	Acetone	Lint-Free Wipe	HDPE	1	0	81-100%
7	132	Bentonite	Acetone	Lint-Free Wipe	HDPE	2	0	81-100%

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Appendix B – Decohesion Test Result Photographs



Figure 27. Test Matrix 2, Run Index 1



Figure 28. Test Matrix 2, Run Index 2

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Figure 29. Test Matrix 2, Run Index 3



Figure 30. Test Matrix 2, Run Index 4

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Figure 31. Test Matrix 2, Run Index 5

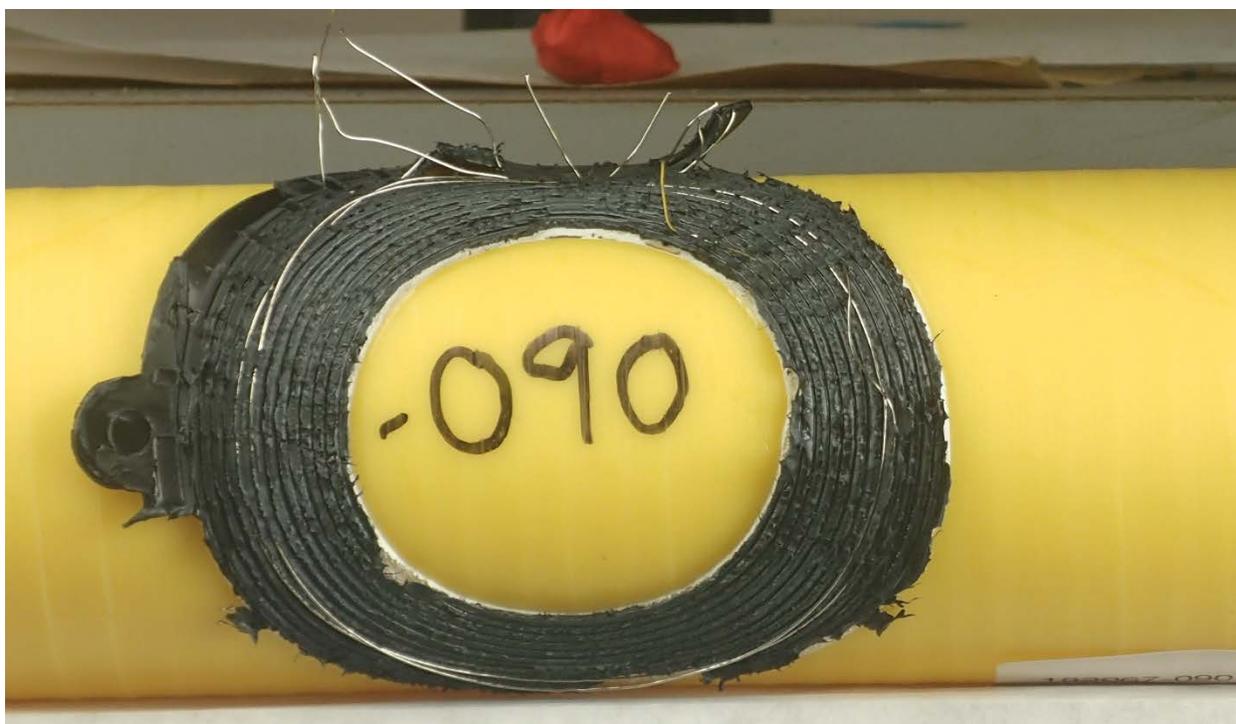


Figure 32. Test Matrix 2, Run Index 6

GTI-OTD Confidential

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Figure 33. Test Matrix 2, Run Index 7

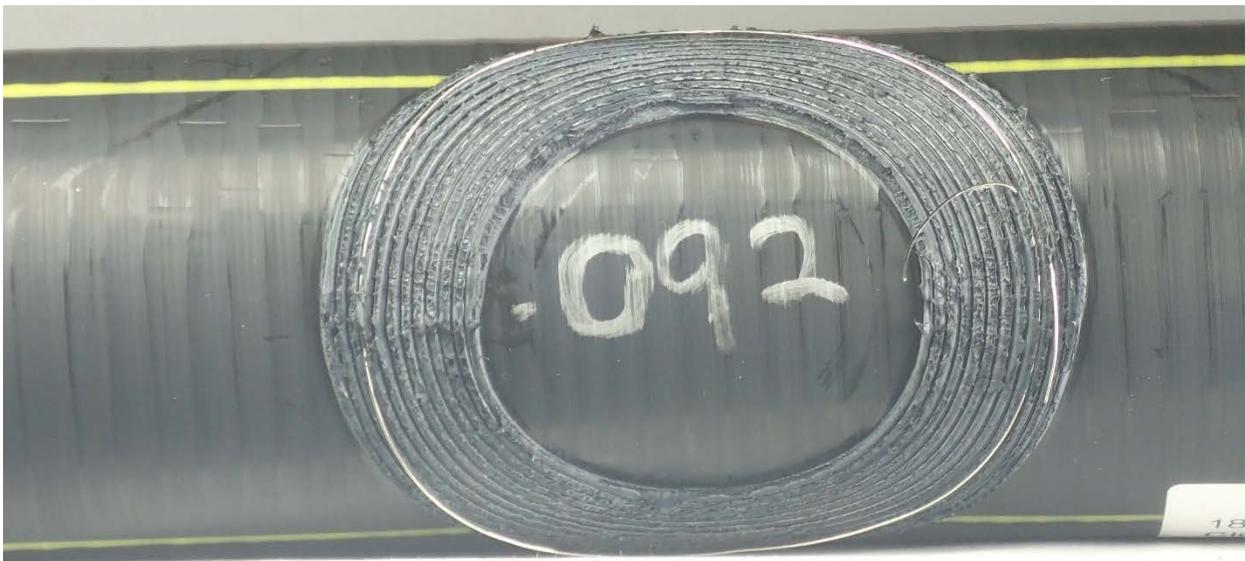


Figure 34. Test Matrix 2, Run Index 8

2018/03/06

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Figure 35. Test Matrix 2, Run Index 9



Figure 36. Test Matrix 2, Run Index 10

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Figure 37. Test Matrix 2, Run Index 11



Figure 38. Test Matrix 2, Run Index 12

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Figure 39. Test Matrix 2, Run Index 13



Figure 40. Test Matrix 2, Run Index 14

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Figure 41. Test Matrix 2, Run Index 15



Figure 42. Test Matrix 2, Run Index 16

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Figure 43. Test Matrix 2, Run Index 17



Figure 44. Test Matrix 2, Run Index 18

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Figure 45. Test Matrix 2, Run Index 19



Figure 46. Test Matrix 2, Run Index 20

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Figure 47. Test Matrix 2, Run Index 21



Figure 48. Test Matrix 2, Run Index 22

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Figure 49: Test Matrix 3, Run Index 23

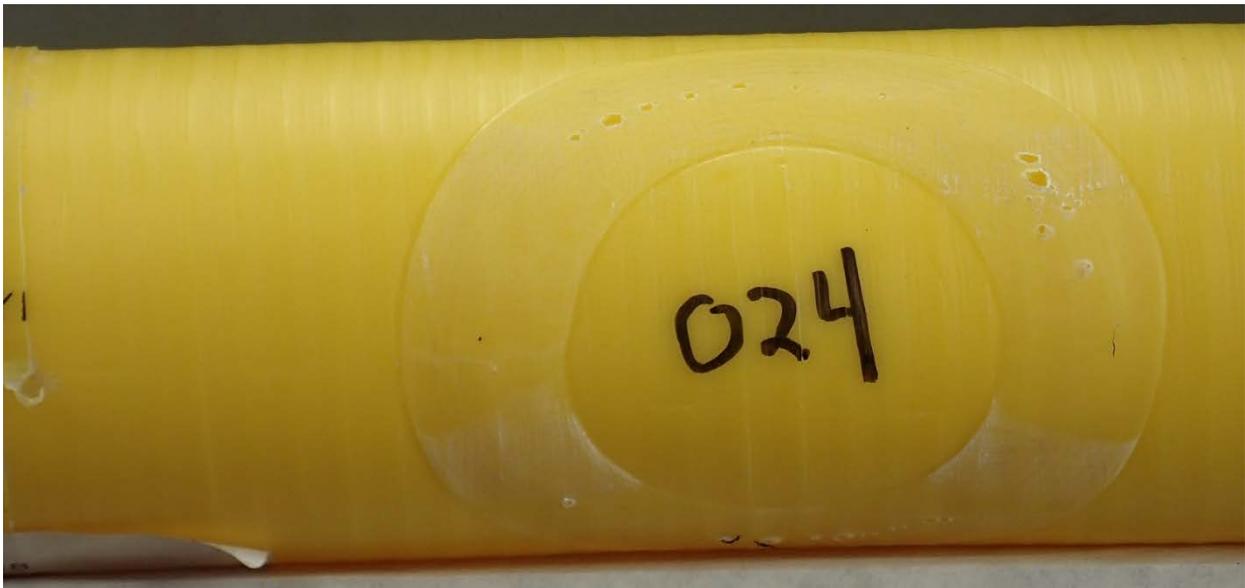


Figure 50: Test Matrix 3, Run Index 24

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Figure 51: Test Matrix 3, Run Index 25



Figure 52: Test Matrix 3, Run Index 26

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Figure 53: Test Matrix 3, Run Index 27



Figure 54: Test Matrix 3, Run Index 28

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Figure 55: Test Matrix 3, Run Index 29



Figure 56: Test Matrix 3, Run Index 30

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Figure 57: Test Matrix 3, Run Index 31



Figure 58: Test Matrix 3, Run Index 32

GTI-OTD Confidential

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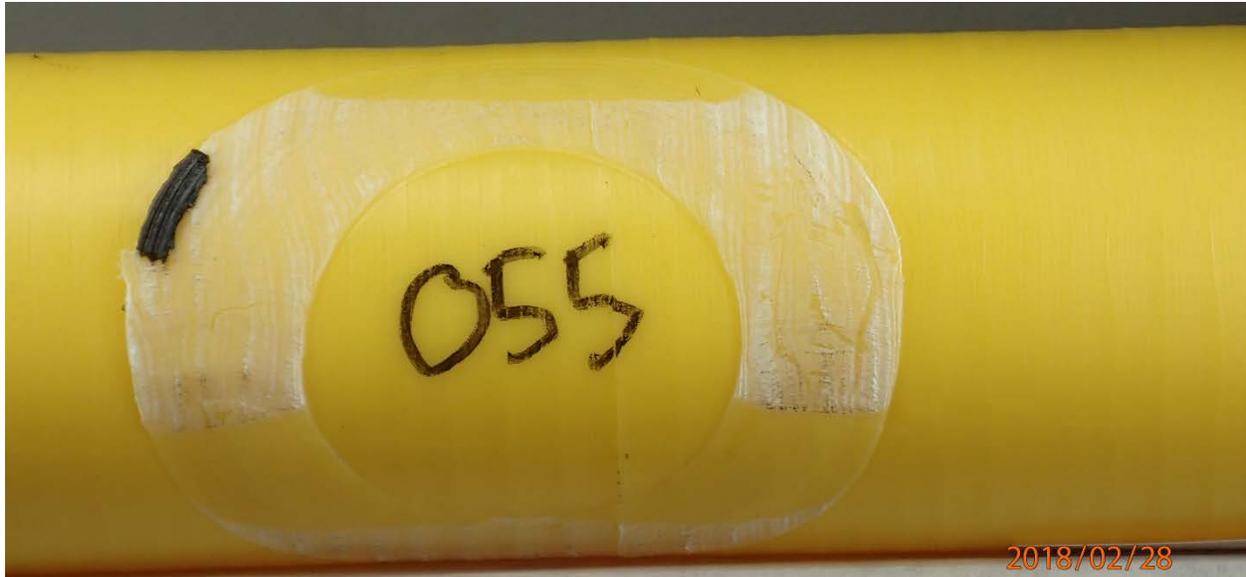


Figure 59: Test Matrix 3, Run Index 33



Figure 60: Test Matrix 3, Run Index 34

GTI-OTD Confidential

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Figure 61: Test Matrix 3, Run Index 35



Figure 62: Test Matrix 3, Run Index 36

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Figure 63: Test Matrix 3, Run Index 37



Figure 64: Test Matrix 3, Run Index 38

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Figure 65: Test Matrix 3, Run Index 39



Figure 66: Test Matrix 3, Run Index 40

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Figure 67: Test Matrix 3, Run Index 41



Figure 68: Test Matrix 3, Run Index 42

GTI-OTD Confidential

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Figure 69: Test Matrix 3, Run Index 43



Figure 70: Test Matrix 3, Run Index 44

GTI-OTD Confidential

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Figure 71. Test Matrix 4, Run Index 45



Figure 72. Test Matrix 4, Run Index 46

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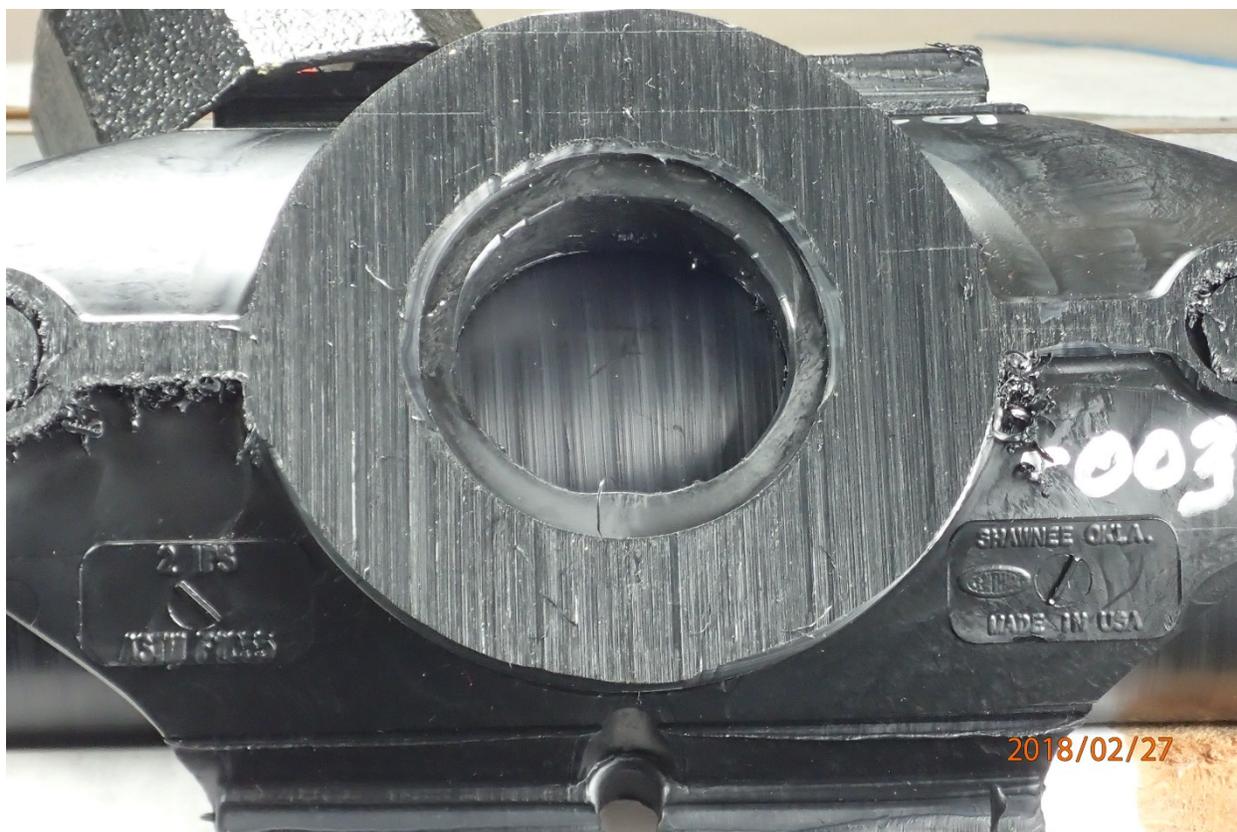


Figure 73. Test Matrix 4, Run Index 47, saddle did not fully separate from the pipe during the decohesion test

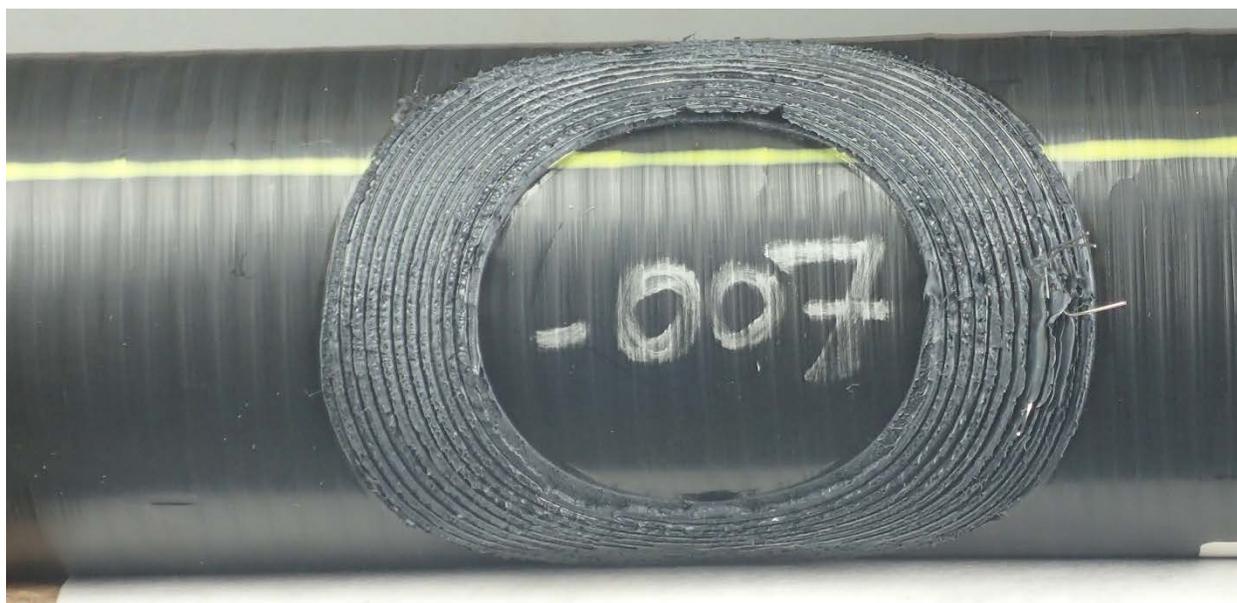


Figure 74. Test Matrix 4, Run Index 48

GTI-OTD Confidential

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Figure 75. Test Matrix 4, Run Index 49



Figure 76. Test Matrix 4, Run Index 50

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Figure 77. Test Matrix 4, Run Index 51



Figure 78. Test Matrix 4, Run Index 52

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Figure 79. Test Matrix 4, Run Index 53

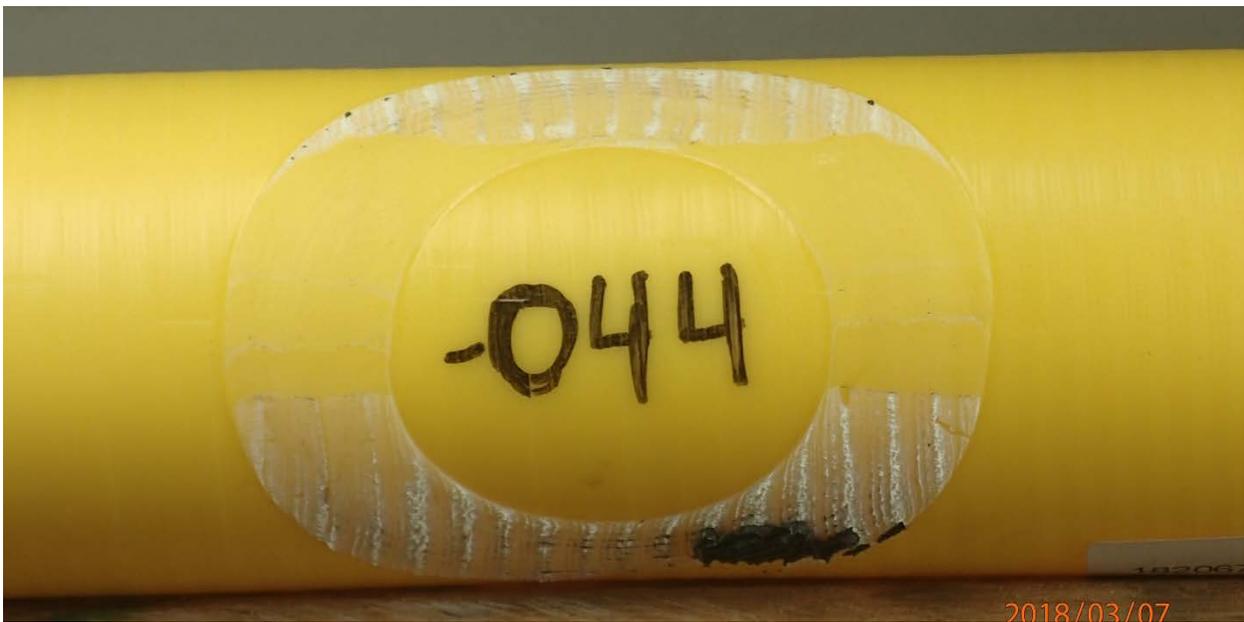


Figure 80. Test Matrix 4, Run Index 54

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Figure 81. Test Matrix 4, Run Index 55

2018/03/07



Figure 82. Test Matrix 4, Run Index 56

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Figure 83. Test Matrix 4, Run Index 57



Figure 84. Test Matrix 4, Run Index 58

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Figure 85. Test Matrix 4, Run Index 59



Figure 86. Test Matrix 4, Run Index 60

2018/02/28

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Figure 87. Test Matrix 4, Run Index 61

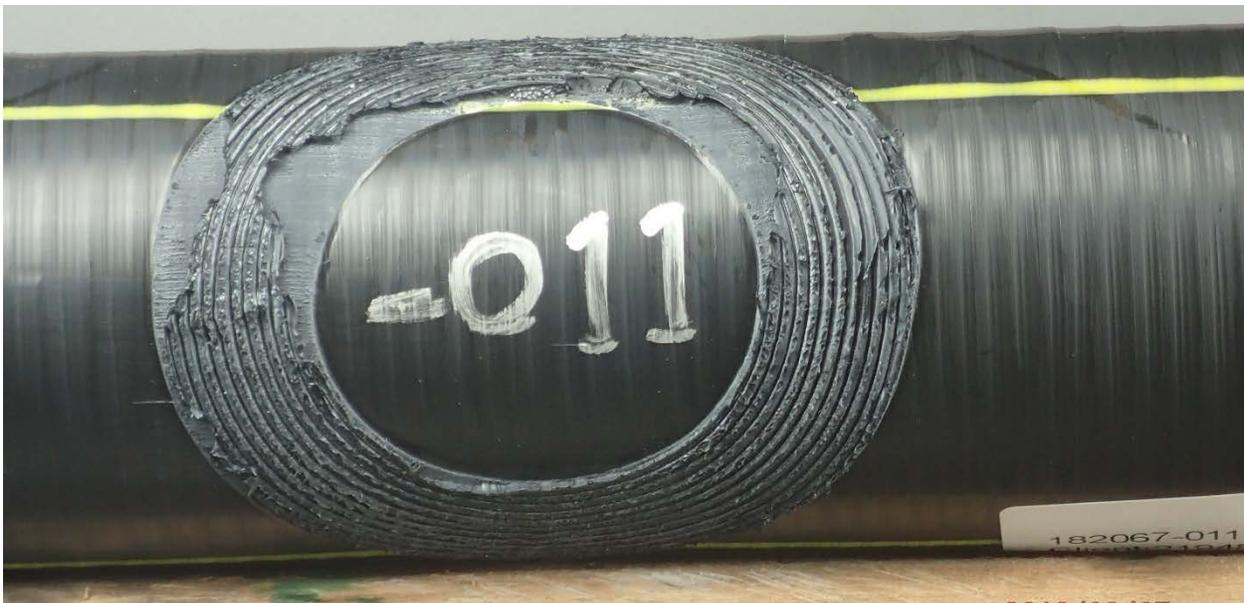


Figure 88. Test Matrix 4, Run Index 62

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Figure 89. Test Matrix 4, Run Index 63



2018/02/27

Figure 90. Test Matrix 4, Run Index 64

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Figure 91. Test Matrix 4, Run Index 65



Figure 92. Test Matrix 4, Run Index 66

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Figure 93. Test Matrix 4, Run Index 67



Figure 94. Test Matrix 4, Run Index 68

2018/02/28

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Figure 95. Test Matrix 4, Run Index 69



Figure 96. Test Matrix 4, Run Index 70

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Figure 97. Test Matrix 4, Run Index 71



Figure 98. Test Matrix 4, Run Index 72

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Figure 99. Test Matrix 4, Run Index 73



Figure 100. Test Matrix 4, Run Index 74

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Figure 101. Test Matrix 4, Run Index 75



Figure 102. Test Matrix 4, Run Index 76

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Figure 103. Test Matrix 4, Run Index 77



Figure 104. Test Matrix 4, Run Index 78

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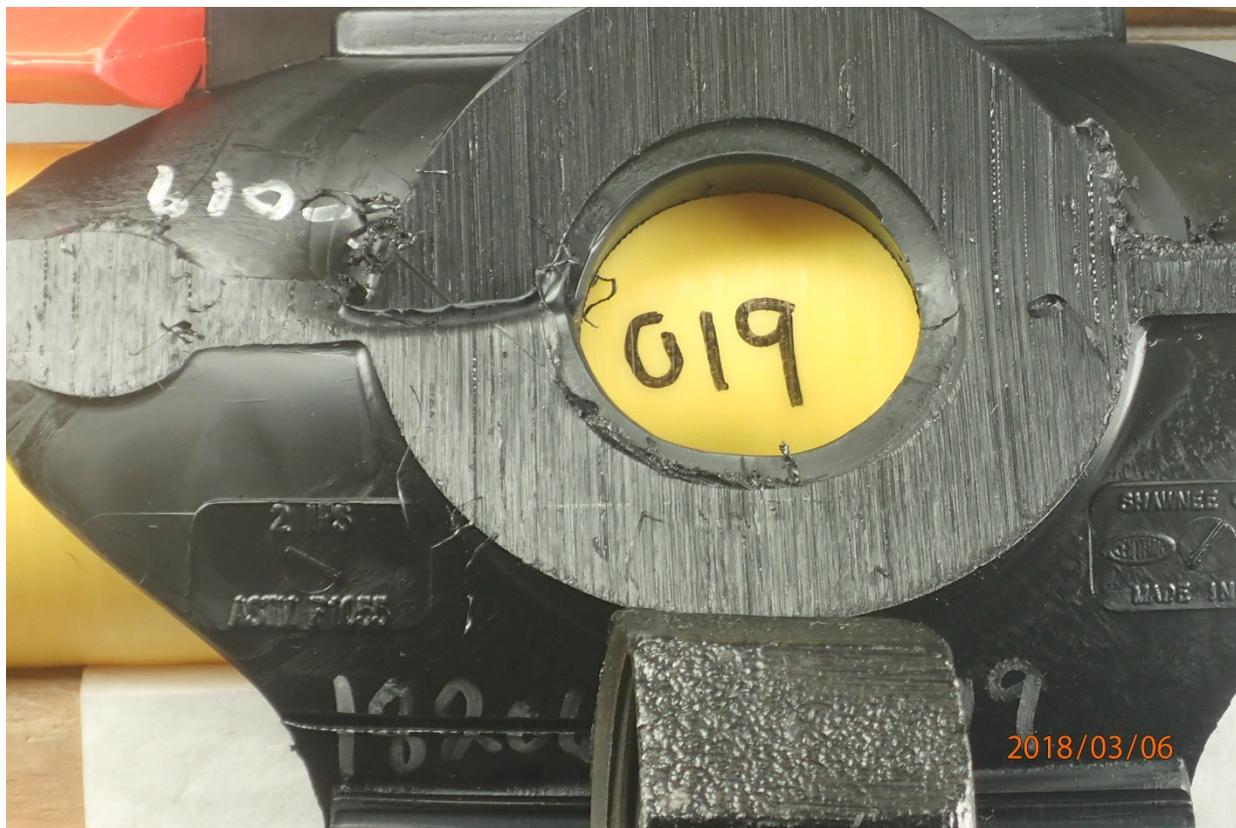


Figure 105. Test Matrix 4, Run Index 79, saddle did not fully separate from the pipe during the decohesion test



Figure 106. Test Matrix 4, Run Index 80

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Figure 107. Test Matrix 4, Run Index 81



Figure 108. Test Matrix 4, Run Index 82

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Figure 109: Test Matrix 5, Run Index 83



Figure 110: Test Matrix 5, Run Index 84

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Figure 111: Test Matrix 5, Run Index 85



Figure 112: Test Matrix 5, Run Index 86

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Figure 113: Test Matrix 5, Run Index 87



Figure 114: Test Matrix 5, Run Index 88

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Figure 115: Test Matrix 5, Run Index 89



Figure 116: Test Matrix 5, Run Index 90

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Figure 117: Test Matrix 5, Run Index 91



Figure 118: Test Matrix 5, Run Index 92

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Figure 119: Test Matrix 5, Run Index 93



Figure 120: Test Matrix 5, Run Index 94

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Figure 121: Test Matrix 5, Run Index 95

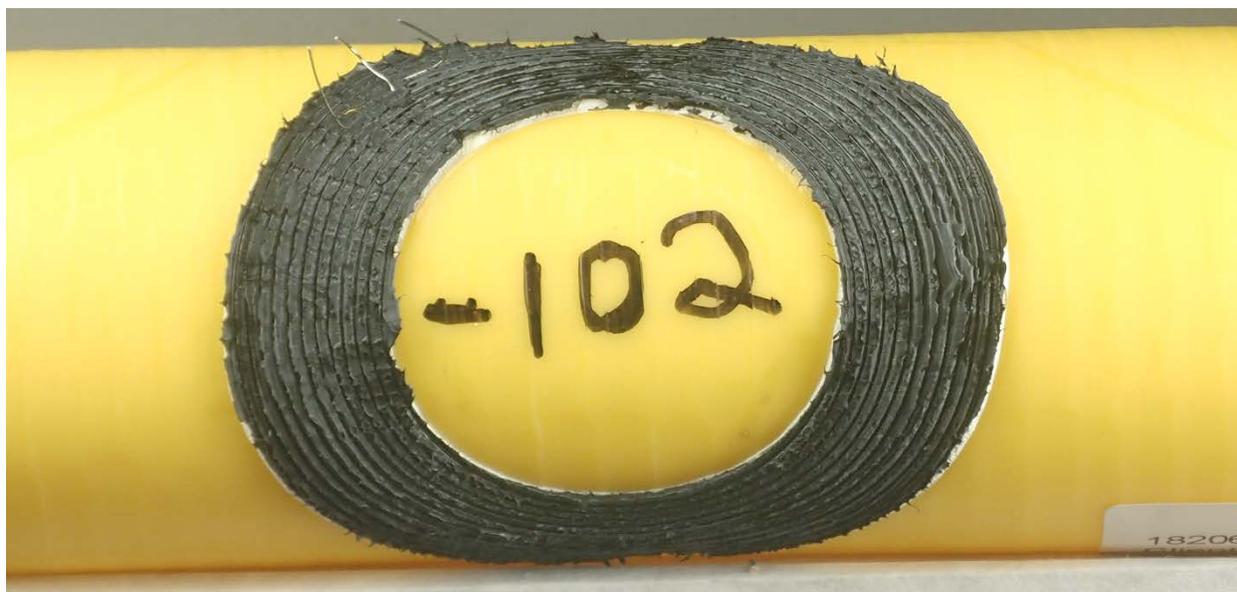


Figure 122: Test Matrix 5, Run Index 96

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Figure 123: Test Matrix 5, Run Index 97



Figure 124: Test Matrix 5, Run Index 98

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Figure 125: Test Matrix 5, Run Index 99



Figure 126: Test Matrix 5, Run Index 100

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Figure 127: Test Matrix 5, Run Index 101



Figure 128: Test Matrix 5, Run Index 102

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Figure 129: Test Matrix 5, Run Index 103



Figure 130: Test Matrix 5, Run Index 104

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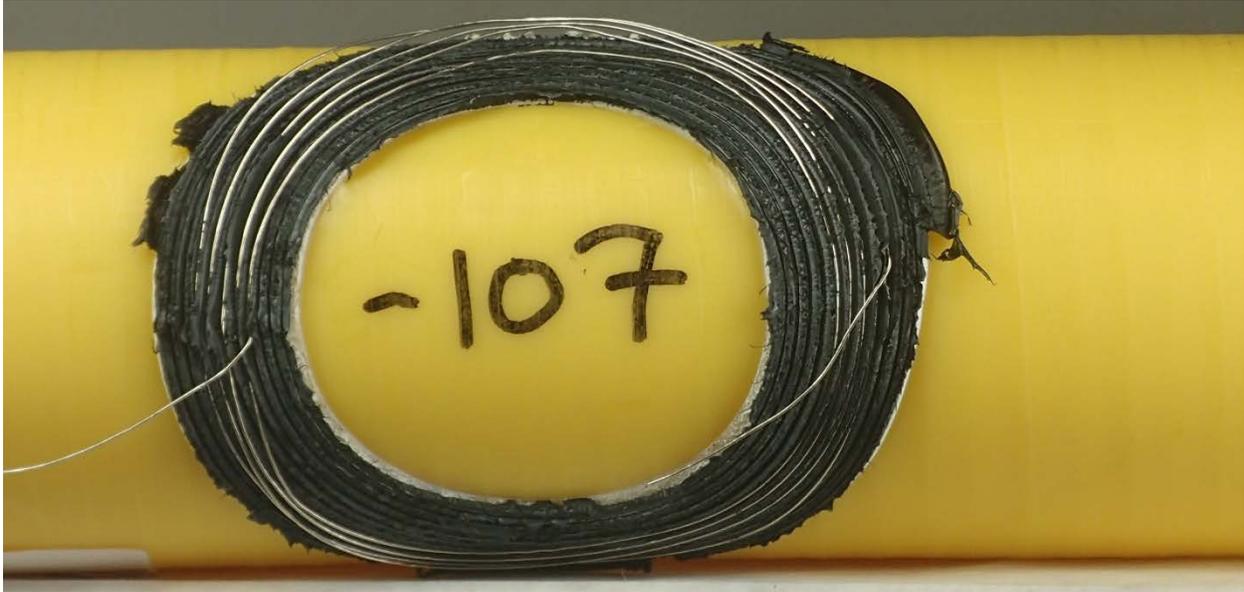


Figure 131. Test Matrix 6, Run Index 105

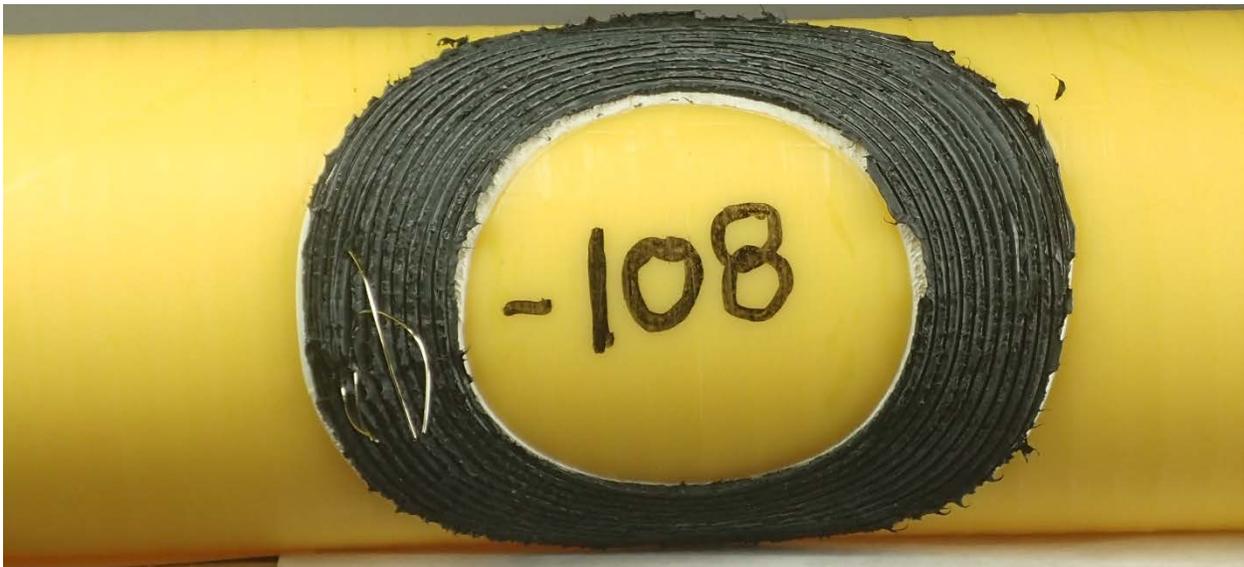


Figure 132. Test Matrix 6, Run Index 106

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Figure 133. Test Matrix 6, Run Index 107



Figure 134. Test Matrix 6, Run Index 108

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Figure 135. Test Matrix 7, Run Index 109



Figure 136. Test Matrix 7, Run Index 110

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Figure 137. Test Matrix 7, Run Index 111



Figure 138. Test Matrix 7, Run Index 112

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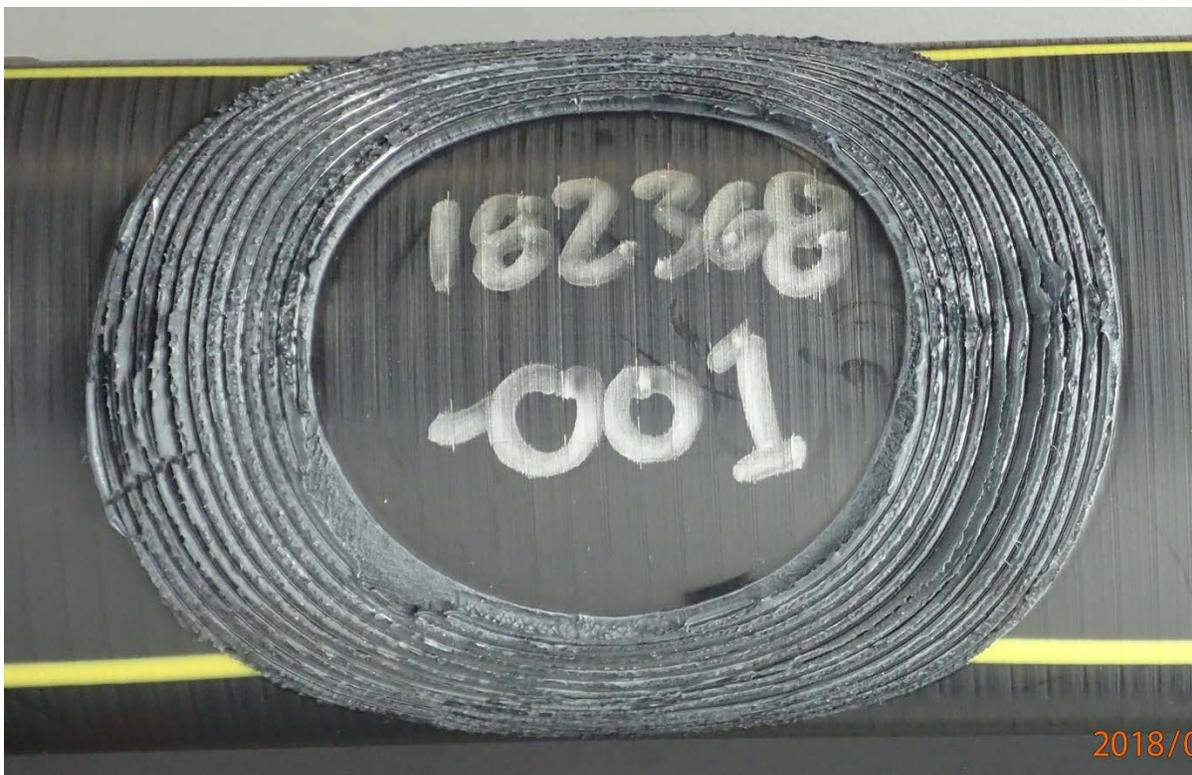


Figure 139. Test Matrix 7, Run Index 113



Figure 140. Test Matrix 7, Run Index 114

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Figure 141. Test Matrix 7, Run Index 115

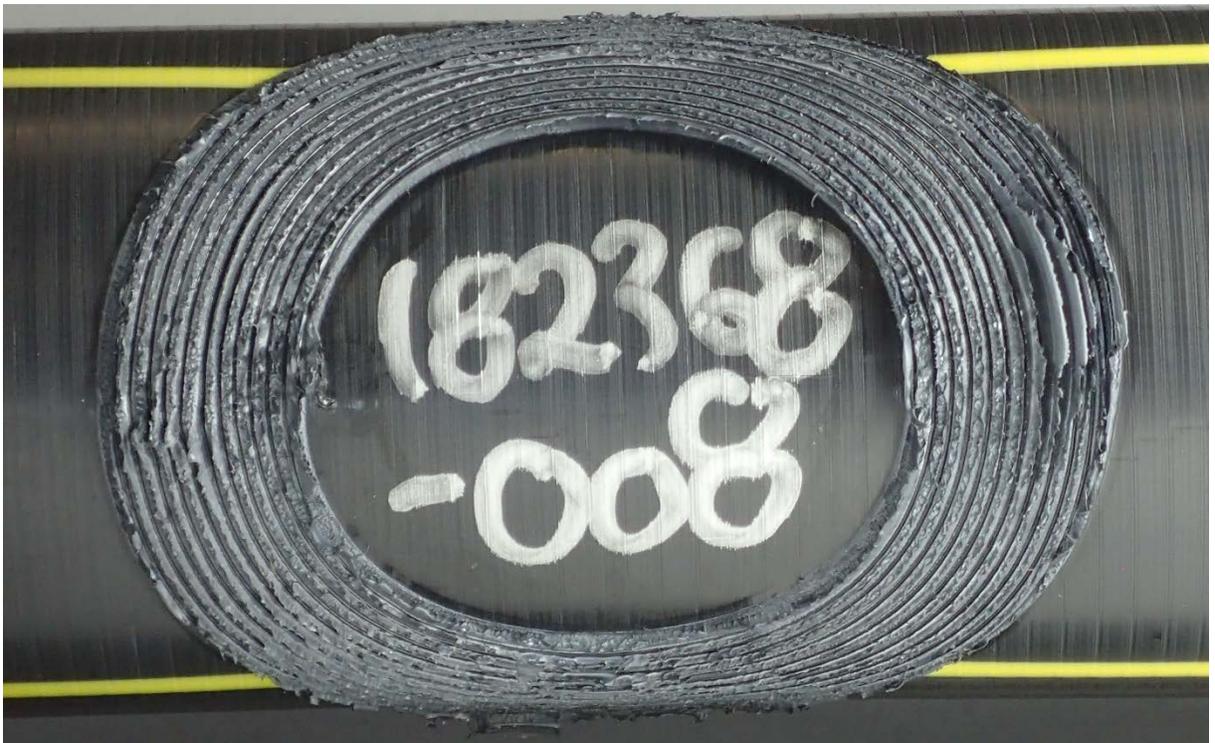


Figure 142. Test Matrix 7, Run Index 116

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Figure 143. Test Matrix 7, Run Index 117



Figure 144. Test Matrix 7, Run Index 118

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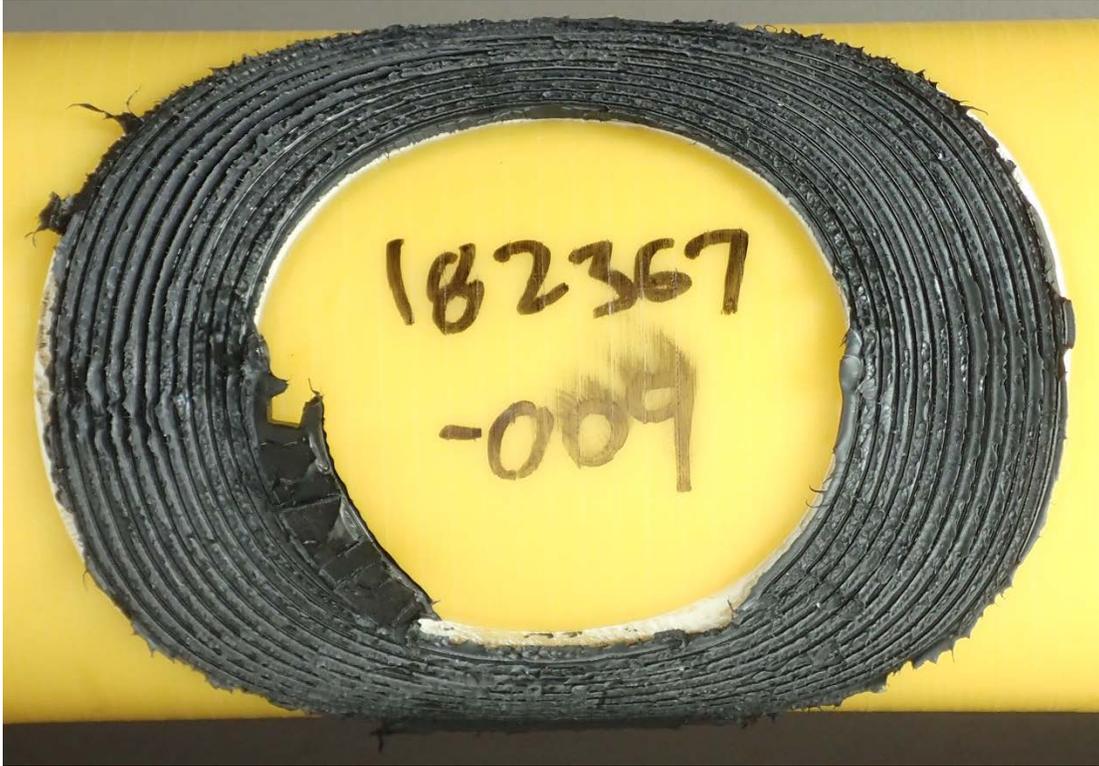


Figure 145. Test Matrix 7, Run Index 119



Figure 146. Test Matrix 7, Run Index 120

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Figure 147. Test Matrix 7, Run Index 121



Figure 148. Test Matrix 7, Run Index 122

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Figure 149. Test Matrix 7, Run Index 123



Figure 150. Test Matrix 7, Run Index 124

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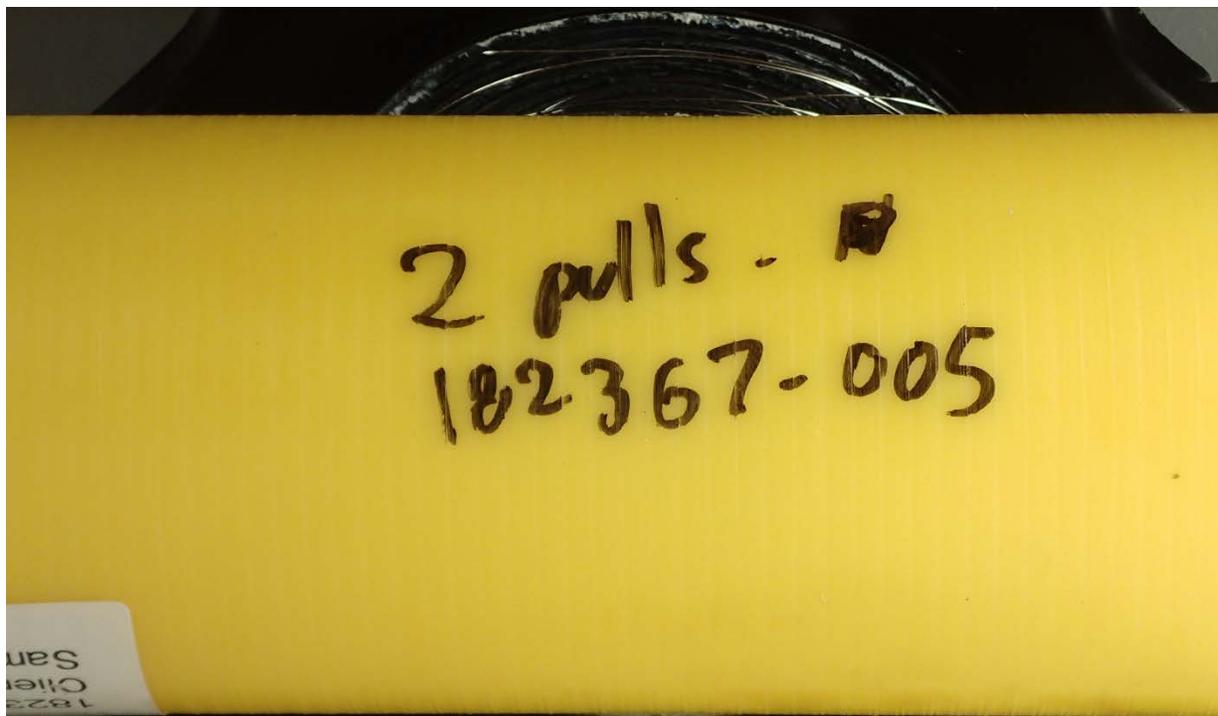


Figure 151. Test Matrix 7, Run Index 125 (saddle did not fully separate from pipe)

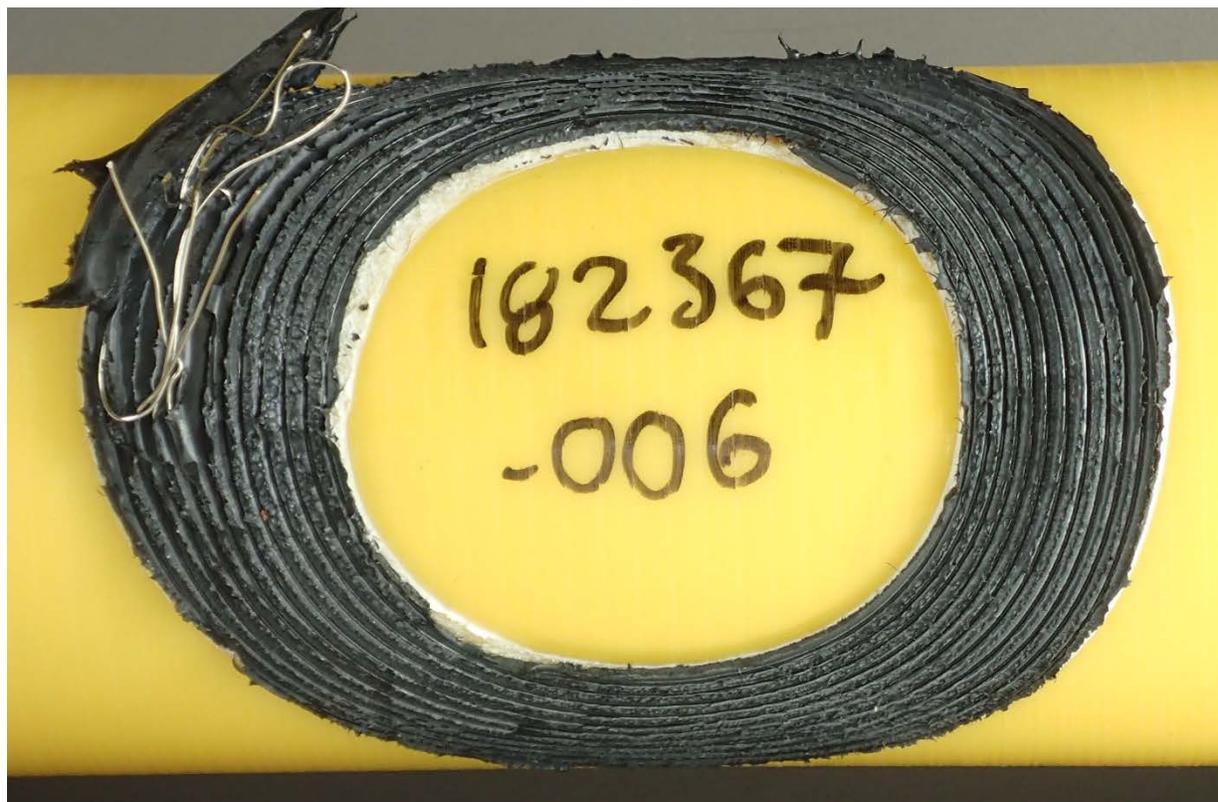


Figure 152. Test Matrix 7, Run Index 126

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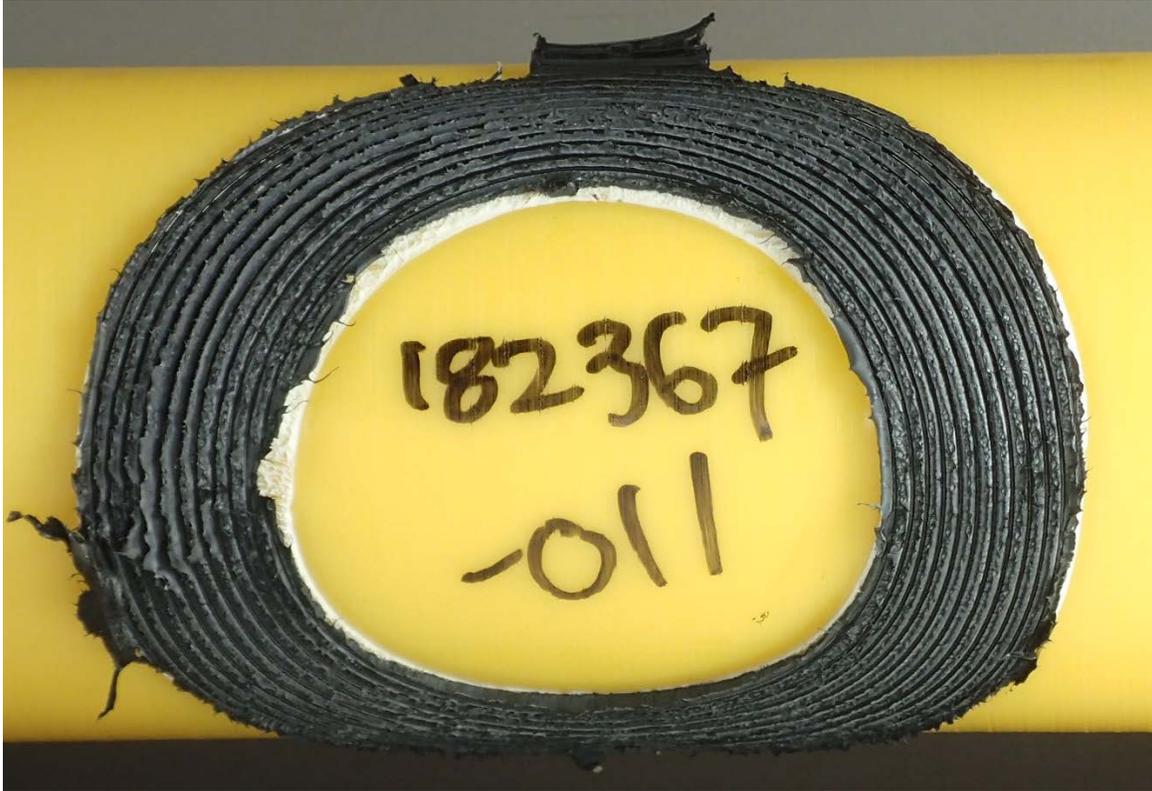


Figure 153. Test Matrix 7, Run Index 127

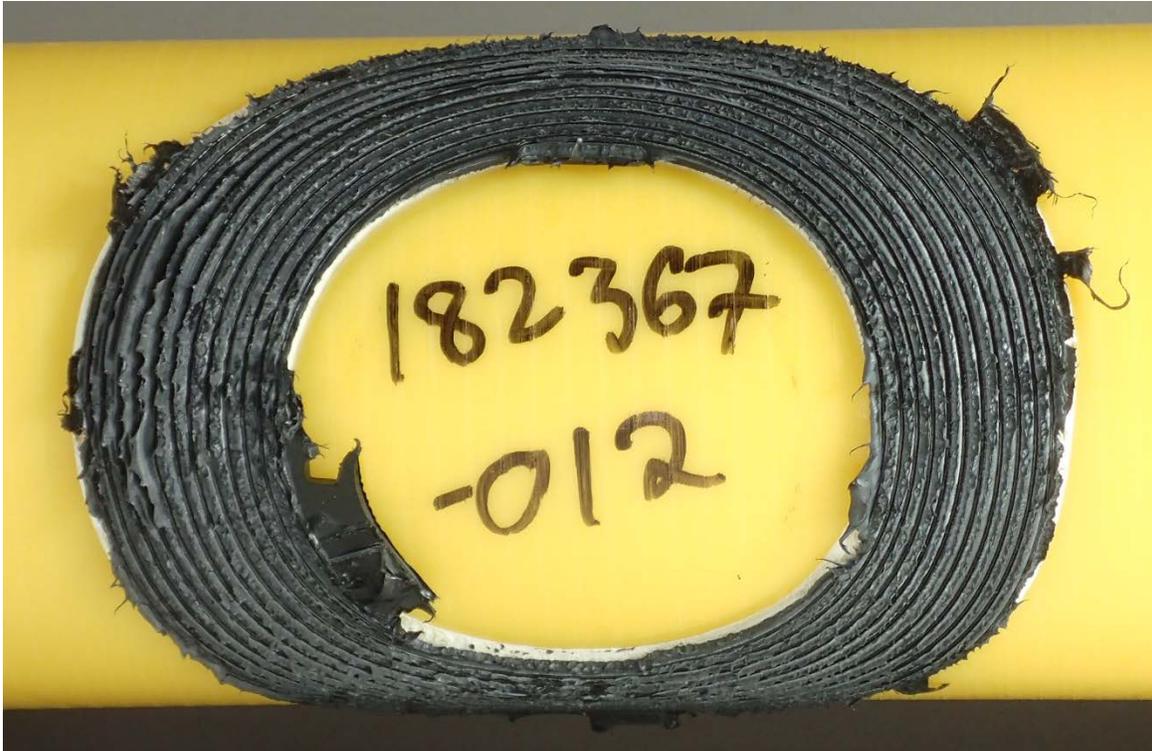


Figure 154. Test Matrix 7, Run Index 128

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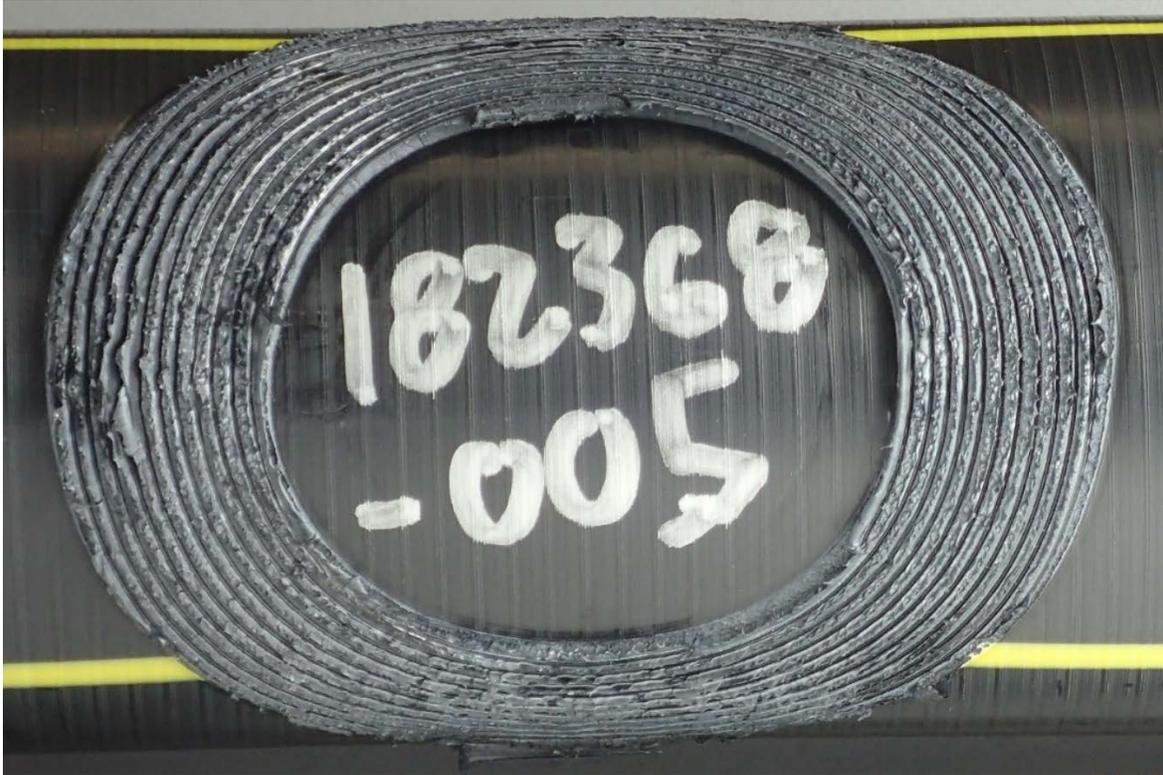


Figure 155. Test Matrix 7, Run Index 129

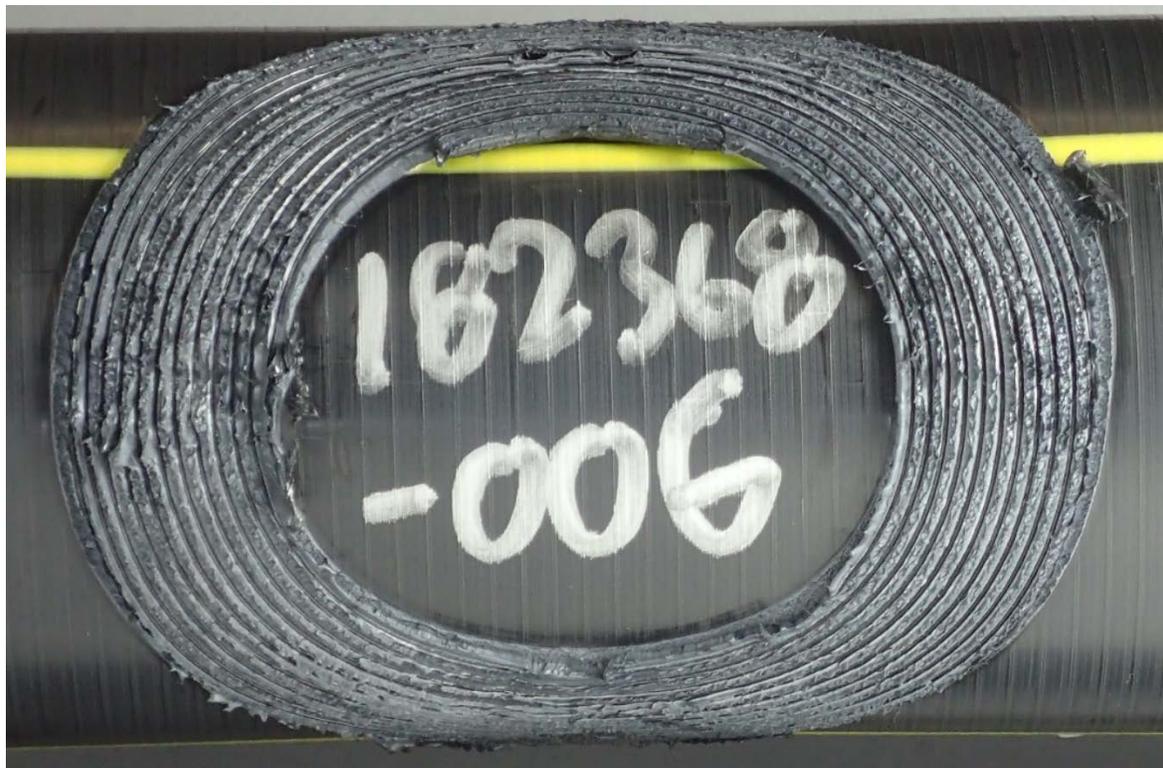


Figure 156. Test Matrix 7, Run Index 130

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Figure 157. Test Matrix 7, Run Index 131



Figure 158. Test Matrix 7, Run Index 132

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Appendix C – Wiping Technique Reference

The following figures are provided for general reference on the wiping technique employed on tests performed under this project (final report and addendum tests). Although the examples here show only one cleaning tool (lint-free wipe) and contaminant (bentonite powder), the technique was applied identically for all cleaning tools, solvents, and contaminants.



Figure 159. Wetting of a lint-free wipe with a solvent

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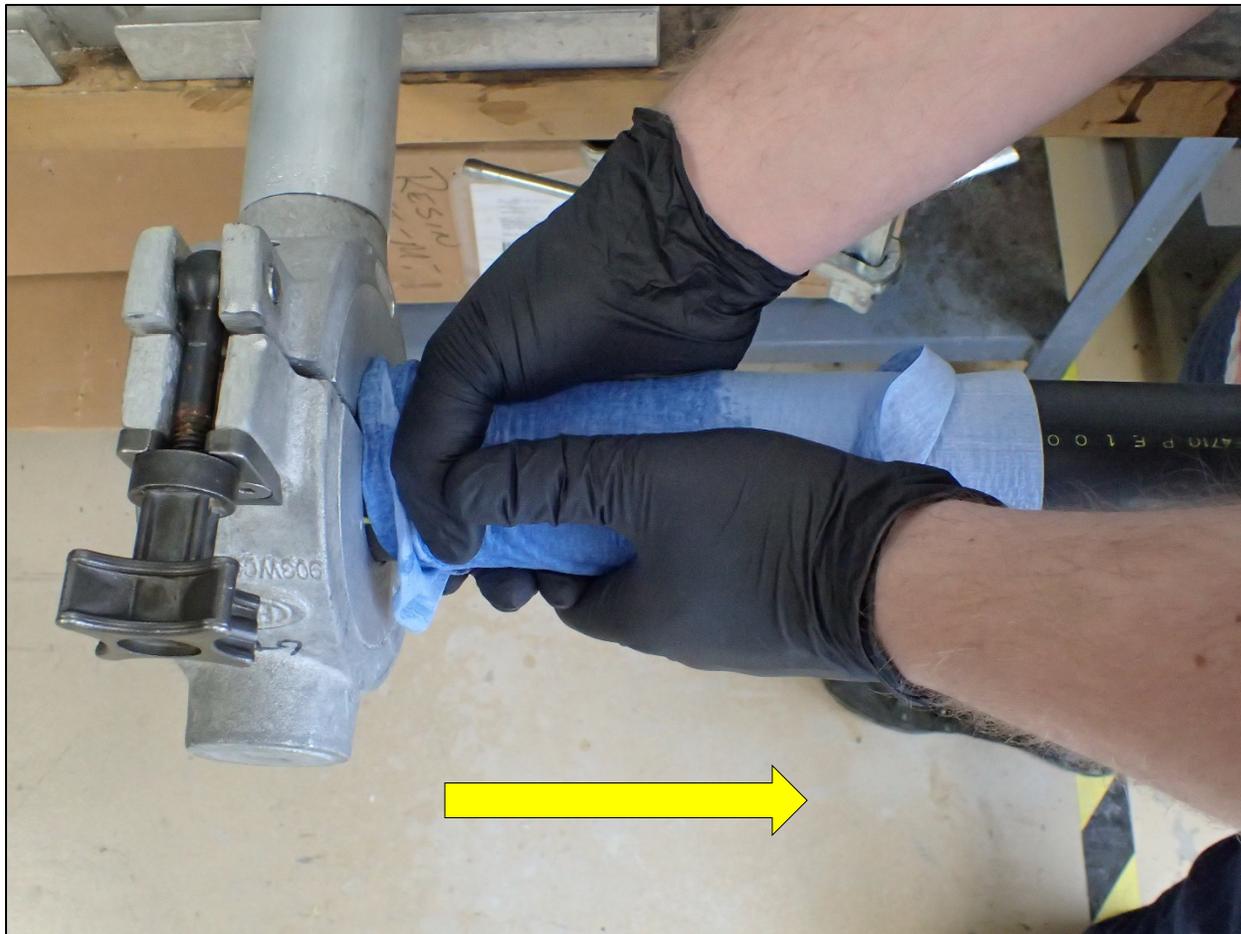


Figure 160. Wrapping of the pipe before wiping pass, arrow indicates wipe direction

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Figure 161. Pipe contaminated with bentonite powder

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Figure 162. Pipe contaminated with bentonite powder, after one solvent cleaning pass

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Figure 163. Pipe contaminated with bentonite powder, after two solvent cleaning passes

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Figure 164. Pipe contaminated with bentonite powder, after three solvent cleaning passes, as necessary to make the surface visually appear to be clean; loose contamination has been removed

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Figure 165. Pipe contaminated with bentonite powder, end of scraping pass

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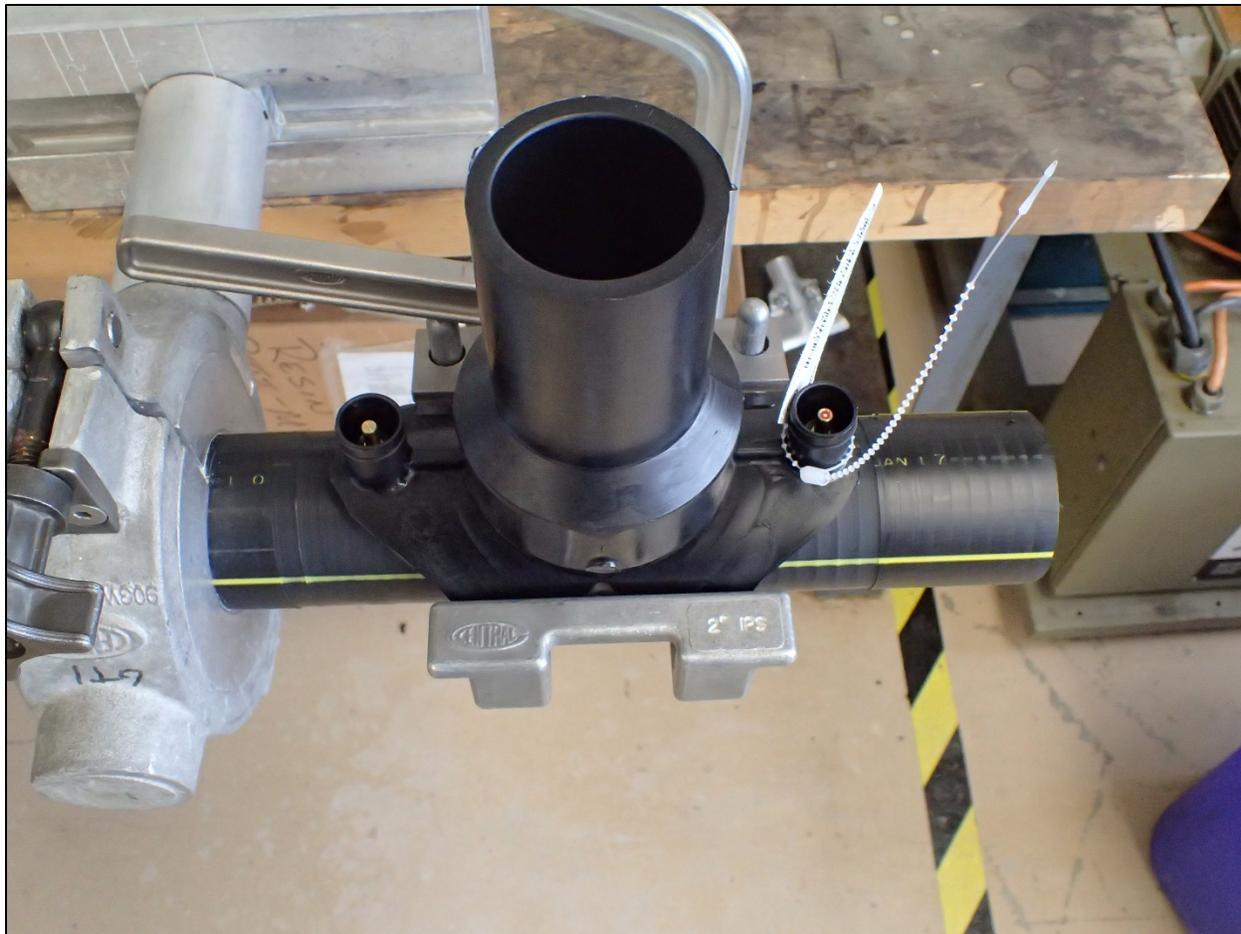


Figure 166. Pipe contaminated with bentonite powder, saddle clamping promptly after scraping

END OF REPORT

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