Solvent Cleaning and PE Joining Procedures

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<td>CTS</td>
<td>Copper Tube Size</td>
</tr>
<tr>
<td>DI water</td>
<td>Deionized water</td>
</tr>
<tr>
<td>DoE</td>
<td>Design of Experiment</td>
</tr>
<tr>
<td>EF</td>
<td>Electrofusion</td>
</tr>
<tr>
<td>FTIR-ATR</td>
<td>Fourier Transform Infrared – Attenuated Total Reflectance</td>
</tr>
<tr>
<td>GTI</td>
<td>Gas Technology Institute</td>
</tr>
<tr>
<td>HDD</td>
<td>Horizontal Directional Drilling</td>
</tr>
<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
</tr>
<tr>
<td>ID</td>
<td>Inner Diameter</td>
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<tr>
<td>IPA</td>
<td>Isopropyl Alcohol</td>
</tr>
<tr>
<td>IPS</td>
<td>Iron Pipe Size</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<tr>
<td>MDPE</td>
<td>Medium Density Polyethylene</td>
</tr>
<tr>
<td>OD</td>
<td>Outer Diameter</td>
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<td>Operations Technology Development</td>
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<td>Polyethylene</td>
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<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>SCG</td>
<td>Slow Crack Growth</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscope</td>
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Executive Summary

Recent events have raised concern regarding fusion procedures and more specifically pipe preparation and cleaning procedures used by utilities and the protocols used to perform and qualify PE joining procedures. Additionally, recent cases of PE fusion joint failure investigated by GTI have found surface contamination to be the root cause of the failures, despite proper scraping of the pipe.

The work done in this project follows up and complements on the work performed in OTD Project 2.14.e Guidelines/Best Practices for Scraping PE Pipe and Fittings (highlighted in green in Figure 1). As can be seen in Figure 1, these two projects together cover the core pipe surface preparation processes. While OTD Project 2.14.e focused on the scraping/peeling performance of several common scrapers and peelers, this project has focused on the effectiveness of solvent cleaning in removal of surface contaminants.

The focus of this project was to test the performance of commonly used solvents and cleaning tools in terms of removal of contamination (talc powder, bentonite powder, and silicone grease) on PE pipe. Based on the sponsor survey and additional interaction with the project sponsors, a test matrix was developed that was comprised of 120 contamination removal/fusion test runs with electrofusion saddle fittings. The test matrix covered all combinations of the contaminants (talc powder, bentonite powder, silicone grease), cleaning agents (99% isopropyl alcohol, 91% isopropyl alcohol, acetone), and cleaning tools (lint-free wipe, cotton cloth rag, paper towel). Each combination was tested four times – twice on MDPE pipe and twice on HDPE pipe. Preliminary contamination removal tests on pipe rings, separate from the 120 contamination removal/fusion tests, were first conducted to get baseline data of the cleaning effectiveness of each combination of cleaning agent and cleaning tool with each contaminant.

The testing results have led to the following observations:

- The preliminary contamination removal tests on non-scraped pipe rings indicated that solvent cleaning is fundamentally effective at removing talc and bentonite powders on a relatively small and smooth surface.
- Silicone grease is particularly difficult to remove regardless of solvent and cleaning tool combination.
- The contamination removal/fusion tests indicate that in pipe cleaning scenarios any given wiping pass will not uniformly remove surface contamination.
  - The variability in cleaning is due to OD surface roughness, non-uniform wiping contact, physical variability of the cleaning tool, and contaminant distribution on the surface.
- Solvent cleaning will remove loose contamination such that the pipe will look clean.
- The pipe cleaning protocol employed in this project produced highly variable decohesion test results, and no 100% ductile joints.

The above observations lead to the following conclusions and recommendations:

- Solvent cleaning should be used to remove loose dirt and the bulk of surface contaminants before scraping.
  - This is further supported by the scraping-only test results from OTD Project 2.14.e Guidelines/Best Practices for Scraping PE Pipe and Fittings, shown in Figure 22.
- More than a single wiping pass should be required due to the variability in contamination removal of any single pass.
  - Each subsequent wiping pass should be within the area of the preceding wiping pass to avoid reintroduction of contamination from outside of the first wiping pass area.
- Any wiping pass should be made with a new cleaning tool to avoid reintroduction of contamination from a used cleaning tool.
• Any wiping pass should be made in the same single direction to avoid or minimize spreading of contamination that does not get removed by the current or previous pass.

Based on the inconsistency in solvent-cleaning’s contamination removal, as observed in this project’s testing, it is not clear if post-scraping solvent cleaning will be sufficiently effective at removing contaminants introduced after scraping. Additional testing is required to resolve the acceptability of post-scraping solvent cleaning – specifically, multiple wiping passes, water washing, and degree of contamination need to be evaluated.

The findings in this project and OTD Project 2.14.e Guidelines/Best Practices for Scrapping PE Pipe and Fittings lead to the suggestion of a preparation technique where the pipe is thoroughly washed and cleaned prior to scraping and where the time between scraping and assembling of the fitting is minimized. The critical contamination avoidance aspects of the proposed procedure are (in chronological order):

1. Water-wash of pipe (exceeding the area to be scraped).
2. Solvent cleaning of the pipe with a specific wiping technique (exceeding area to be scraped, but within the water-washed area).
3. Scraping of the pipe immediately after solvent cleaning (within the solvent-cleaned area).
4. Assembly of the fitting and performing the fusion immediately after scraping.

This proposed procedure, which was also included in the final report of OTD Project 2.14.e, is detailed in this report on Page 45.

Overall, the various test results of this project and the results from OTD Project 2.14.e lend support the observation that to achieve successful PE fusions, best practices should be adopted in conjunction with thorough operator training with specific attention to prevention of contamination of the fusion areas of the pipe and fitting.

**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 of utmost importance 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 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). Additionally, surface contamination affects PE fusion in the same way regardless of the joining method and joint geometry.
Introduction

Recent events have raised concern regarding fusion preparation procedures and more specifically cleaning procedures used by utilities and the protocols used to perform and qualify PE joining procedures. Additionally, recent cases of PE fusion joint failure investigated by GTI have found surface contamination to be the root cause of the failures, despite proper scraping of the pipe.

Field issues related to pipe preparation and PE fusion performance have created a need for better guidelines to assist utilities and their field operators/contractors. Procedures and subsequent training has been enhanced over the years, however, failures still occur even though the procedures and training are followed. Operators are ultimately responsible for ensuring that all PE joining procedures used have been qualified per CFR 192.283, therefore, continuous improvement of joining procedures is vital.

GTI has recognized that in order to properly address joint integrity issues, a comprehensive approach must be taken where the influence of all processes and materials used in creating a joint are acknowledged and understood. To achieve this goal, GTI has begun to develop a process map relating the various elements involved in creating a joint. Figure 1 shows a portion of this map related to electrofusion joints, which are the primary joint type related to the focus of this project: surface cleaning (highlighted in blue in Figure 1).

The work done in this project follows up and complements the work performed in OTD Project 2.14.e Guidelines/Best Practices for Scraping PE Pipe and Fittings (highlighted in green in Figure 1). As can be seen in Figure 1, these two projects together cover the core pipe surface preparation processes. While OTD Project 2.14.e focused on the scraping and peeling performance of several common scrapers/peelers, this project has focused on the effectiveness of solvent cleaning in removal of surface contaminants.
Figure 1. Overview of electrofusion process, with highlights of OTD project scopes
Sponsor Survey

The project sponsors were surveyed with respect to their pipe cleaning procedures. The following tables summarize the survey responses and the general fusion procedure steps as described by each utility’s respective operator manuals. The survey helped with the selection of contaminants, cleaning agents, and cleaning tools for testing.

Table 1. Summary of survey responses

<table>
<thead>
<tr>
<th>Cleaning agents</th>
<th>Utility A</th>
<th>Utility B</th>
<th>Utility C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (optional)</td>
<td>96% IPA wipe, or 99.9% IPA + clean lint-free non-synthetic cloth/paper towel</td>
<td>Damp cotton rag (optional) 91% IPA / 9% DI water + 100% polypropylene non-woven wipe</td>
<td>Water (optional) 96% IPA / 4% DI water + polyester wipe</td>
</tr>
<tr>
<td>Clean outside scraping zone</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cleaning margin outside scraping zone</td>
<td>1 inch</td>
<td>None</td>
<td>Not specified</td>
</tr>
<tr>
<td>Soils</td>
<td>Clay, Loam, Rock (bedrock), Brick, Sand and Slurry.</td>
<td>Clay; clay/sand mixture; sand. Backfilling material is sand. Drilling mud is bentonite.</td>
<td>-</td>
</tr>
<tr>
<td>Contamination sources</td>
<td>Sweat, hydrocarbons of any kind (motor oil, grease, gasoline, etc.), precipitation from snow and rain.</td>
<td>Oil from bare hands/fingers, ii) oil residue from tracer wire connectors, iii) oil residue from metallic tools.</td>
<td>Dirty scrapers, Leak detection solution, Contaminants from blowing wind</td>
</tr>
</tbody>
</table>

Fusion Procedure Steps

<table>
<thead>
<tr>
<th>Step</th>
<th>Utility A</th>
<th>Utility B</th>
<th>Utility C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clean with water</td>
<td>Clean with damp cotton rag</td>
<td>Clean with water</td>
</tr>
<tr>
<td>2</td>
<td>Clean with IPA</td>
<td>Clean with IPA</td>
<td>Clean with IPA</td>
</tr>
<tr>
<td>3</td>
<td>Mark</td>
<td>Mark</td>
<td>Mark</td>
</tr>
<tr>
<td>4</td>
<td>Scrape</td>
<td>Scrape</td>
<td>Scrape</td>
</tr>
<tr>
<td>5</td>
<td>Clean with IPA</td>
<td>Clean with IPA</td>
<td>Optional Clean with IPA</td>
</tr>
<tr>
<td>6</td>
<td>Fuse</td>
<td>Fuse</td>
<td>Fuse</td>
</tr>
</tbody>
</table>
Table 1. Summary of survey responses – continued

<table>
<thead>
<tr>
<th></th>
<th>Utility D</th>
<th>Utility E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning agents</td>
<td>Water, 99.8% IPA</td>
<td>100% cotton rag, 91% IPA / 9% DI water 100% polypropylene non-woven wipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>99.5% acetone / DI water with non-woven pulp polyester-blend towelette</td>
</tr>
<tr>
<td>Clean outside scraping zone</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cleaning margin outside scraping zone</td>
<td>Not specified</td>
<td>25% of fitting length for couplings, 1 inch for heat fusion saddles</td>
</tr>
<tr>
<td>Soils</td>
<td>Native soil if not rocky, bed in sand if soil contains rocks larger than 1&quot;. No crushed rock over 1/8&quot;. Drilling mud is not specified.</td>
<td>Native: Silts and Loams, Sandy and Gravel. Imported: Sand. HDD: Bentonite.</td>
</tr>
<tr>
<td>Contamination sources</td>
<td>Body oils (if required gloves are not worn), grease, oil residue</td>
<td>Trenchless installations: PE pipe exposed to sewer elements from cross bore. PE pipe exposed to heavy hydrocarbon contaminated soil.</td>
</tr>
</tbody>
</table>

Fusion Procedure Steps

<table>
<thead>
<tr>
<th>Step</th>
<th>Utility D</th>
<th>Utility E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clean with water</td>
<td>Clean with water</td>
</tr>
<tr>
<td>2</td>
<td>Clean with IPA</td>
<td>Clean with acetone or IPA</td>
</tr>
<tr>
<td>3</td>
<td>Mark</td>
<td>Mark</td>
</tr>
<tr>
<td>4</td>
<td>Scrape</td>
<td>Scrape</td>
</tr>
<tr>
<td>5</td>
<td>Optional Clean with IPA</td>
<td>Optional Clean with acetone or IPA</td>
</tr>
<tr>
<td>6</td>
<td>Fuse</td>
<td>Fuse</td>
</tr>
</tbody>
</table>
Testing

The focus of this project was to test the performance of commonly used solvents and cleaning tools in terms of removal of contamination (bentonite powder, silicone grease, and talc powder). Based on the sponsor survey and additional interaction with the project sponsors, a test matrix was developed that was comprised of 120 test runs. The test matrix covered all combinations of the contaminants, cleaning agents, and cleaning tools listed in Table 2. Each combination was tested four times – twice on MDPE pipe and twice on HDPE pipe.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Cleaning Agent</th>
<th>Cleaning Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc</td>
<td>99% Isopropyl alcohol</td>
<td>Lint-free wipe</td>
</tr>
<tr>
<td>Bentonite</td>
<td>91% Isopropyl alcohol</td>
<td>Cotton cloth rag</td>
</tr>
<tr>
<td>Silicone grease</td>
<td>Acetone</td>
<td>Paper towel</td>
</tr>
</tbody>
</table>

Talc powder was selected because of its historic use in the UK water industry, as specified in the standard WIS-32-4-08 Specification for the Fusion Jointing of Polyethylene Pressure Pipeline Systems Using PE80 and PE100 Materials. In the work conducted by the UK water industry, talc was chosen as a proxy for surface contamination encountered in the field.

Bentonite powder was selected because it is the primary mineral in drilling fluids used in horizontal directional drilling (HDD) and, being a silicate, it has a similar detrimental effect as other soils or dust.

Silicone grease (Dow Corning Molykote High Vacuum Grease) was selected for testing given its high viscosity and insolubility in water, alcohols, and acetone, which leads to difficulty in its removal. Applications of silicone grease include O-ring seals, mechanical stab coupling, and tracer wire couplings.

The 99% isopropyl alcohol was PTI Process Chemicals Isopropanol (Isopropyl Alcohol 99%), Technical Grade UN-1219, Item # R-615-1, CAS # 67-63-0.

The 91% isopropyl alcohol was obtained from mixing the above 99% isopropyl alcohol with distilled water (at GTI).

The acetone was Sunnyside Acetone (100%), CAS # 67-64-1.

Pipe Contamination Apparatus

A pipe contamination apparatus was constructed in order to contaminate pipe in a consistent manner with a fine powder (talc, bentonite). The apparatus was built to meet the specifications given in the UK standard WIS-32-4-08 Specification for the Fusion Jointing of Polyethylene Pressure Pipeline Systems Using PE80 and PE100 Materials. The details of this device are given in Appendix A – Pipe Contamination Apparatus.
Preliminary Contamination Removal Testing

Preliminary cleaning tests were performed on rings cut from 2” IPS HDPE pipe to get a sense of how effective each cleaning agent and tool combination was at removing a given contaminant. Once the rings were cut, they were contaminated, cleaned, and tested by FTIR-ATR according to the following protocol:

1. Contaminate pipe ring’s OD,
2. Wet the tool with the solvent,
3. Make one wiping pass around circumference of the ring,

The following figures show the post-cleaning results for each contaminant/solvent combination. Each figure contains the FTIR spectrum for virgin PE, contaminated PE, and post-cleaning results using three different cleaning tools: lint-free wipe, cotton rag, and paper towel. Specifically, the tools were:

- Lint-free wipe: Sontara EC Engineered Cloth Wipers - PR831
- Cotton rag: Intex Supply Exact Cuts rags
- Paper towel: Kimberly-Clark Scott Towels

![Figure 2. Tested cleaning tools](image)
Figure 3 shows that 91% isopropyl alcohol was effective at removing bentonite with all tools. This is seen by the absence of a bentonite peak in the spectra of the samples that were cleaned.
Figure 4. Post-cleaning FTIR spectra, contaminant=bentonite, solvent=99% isopropyl alcohol/1% distilled water

Figure 4 shows that 99% isopropyl alcohol was effective at removing bentonite with all tools.
Figure 5. Post-cleaning FTIR spectra, contaminant=bentonite, solvent=acetone

Figure 5 shows that acetone was effective at removing bentonite with all tools.
Figure 6. Post-cleaning FTIR spectra, contaminant=silicone grease, solvent=91% isopropyl alcohol/9% distilled water

Figure 6 shows that 91% isopropyl alcohol was not effective at removing silicone grease when used with a lint free wipe or paper towel. The cotton rag was much better than the other tools, but did not completely remove the silicone grease.
Figure 7 shows that 99% isopropyl alcohol was not effective at removing silicone grease when used with a lint free wipe or paper towel. The cotton rag was much better than the other tools, but did not completely remove the silicone grease.
Figure 8 shows that acetone was not effective at removing silicone grease with any of the tools.
Figure 9. Post-cleaning FTIR spectra, contaminant=talc, solvent=91% isopropyl alcohol/9% distilled water

Figure 9 shows that 91% isopropyl alcohol was effective at removing most of the talc with the lint-free wipe and paper towel, but did not completely remove the talc. With the cotton rag, the talc peak was completely removed.
Figure 10. Post-cleaning FTIR spectra, contaminant=talc, solvent=99% isopropyl alcohol/1% distilled water

**Figure 10** shows that 99% isopropyl alcohol was effective at removing most of the talc with the lint-free wipe and paper towel, but did not completely remove the talc. With the cotton rag, the talc peak was completely removed.
Figure 11 shows that acetone was effective at removing most of the talc with all tools, but did not completely remove the talc.
Contamination Removal and Electrofusion Testing

Contamination removal tests were performed using a 2” IPS electrofusion saddle fittings. This joint type was selected based on its commonalty in the field and the ability to easily perform a (saddle) decohesion tests, which gives a good qualitative and quantitative result of the ductility of the fusion over the entire fusion zone.

The test protocol was as follows:
1. Scrape the pipe (using OEM ‘Peeler’, see Figure 12),
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.

Based on the procedure above, the majority of the test runs with talc and bentonite required only one cleaning pass, while the majority of runs with silicon grease required two passes.

Figure 12. OEM ‘Peeler’, 2” IPS
Following the scraping procedure, electrofusion saddles were fused and then peeled off using the ISO 13956 Type A2 decohesion test method (see Figure 13 and Figure 14).

![Figure 13. Example of saddle decohesion test](image-url)
Figure 14. Schematic of ISO 13956 type A2 decohesion test arrangement

**Key**

1. clamping device, allowing rotation of the loading point
2. PE saddle
3. PE pipe
4. loading pin

**Figure 2 — Typical type A2 test arrangement**
Fusions were scored based on the percent of the fusion zone that exhibited ductile separation\(^1\). The scores were binned in 20% intervals: 0-20%, 21-40%, 41-60%, 61-80%, and 81-100%. Higher ductility scores indicate better removal of the contaminant. For general reference, Figure 15 shows some examples of results at three different ductility bins.

![Ductility Bin 80-100%](image1)
![Ductility Bin 40-60%](image2)
![Ductility Bin 0-20%](image3)

**Figure 15.** Examples of saddle decohesion test results with their ductility bin score

Figure 16 through Figure 18 show combined results from the 120-run test matrix. The combined results charts help show general trends per contaminant, agent, and tool. Figure 19 through Figure 21 show the detailed results, broken down by the specific contaminant-agent-tool combination.

---

\(^1\) Since the objective of this test was to assess removal of contamination, fusion voids were disregarded in the scoring.
Figure 16. Combined decohesion test results
Figure 17. Cleaning agent performance with different contaminants
Figure 18. Cleaning tool performance with different contaminants
Figure 19. Detailed results, 99% isopropyl alcohol
Figure 20. Detailed results, 91% isopropyl alcohol
Figure 21. Detailed results, acetone
Discussion and Conclusions

The testing results have led to the following observations:

- The preliminary contamination removal tests on non-scraped pipe rings indicated that solvent cleaning is fundamentally effective at removing talc and bentonite powders on a relatively small and smooth surface.
- Silicone grease is particularly difficult to remove regardless of solvent and cleaning tool combination.
- The contamination removal/fusion tests indicate that in pipe cleaning scenarios any given wiping pass will not uniformly remove surface contamination.
  - The variability in cleaning is due to OD surface roughness, non-uniform wiping contact, physical variability of the cleaning tool, and contaminant distribution on the surface.
- Solvent cleaning will remove loose contamination such that the pipe will look clean.
- The pipe cleaning protocol employed in this project produced highly variable decohesion test results, and no 100% ductile joints.

The above observations lead to the following conclusions and recommendations:

- Solvent cleaning should be used to remove loose dirt and the bulk of surface contaminants before scraping.
  - This is further supported by the scraping-only test results from OTD Project 2.14. e Guidelines/Best Practices for Scraping PE Pipe and Fittings, shown in Figure 22.
- More than a single wiping pass should be required due to the variability in contamination removal of any single pass.
  - Each subsequent wiping pass should be within the area of the preceding wiping pass to avoid reintroduction of contamination from outside of the first wiping pass area.
- Any wiping pass should be made with a new cleaning tool to avoid reintroduction of contamination from a used cleaning tool.
- Any wiping pass should be made in the same single direction to avoid or minimize spreading of contamination that does not get removed by the current or previous pass.

Based on the inconsistency in solvent-cleaning’s contamination removal, as observed in this project’s testing, it is not clear if post-scraping solvent cleaning will be sufficiently effective at removing contaminants introduced after scraping. Additional testing is required to resolve the acceptability of post-scraping solvent cleaning – specifically, multiple wiping passes, water washing, and degree of contamination need to be evaluated.
Figure 22 shows a comparison of the overall decohesion test results from pipes contaminated with bentonite. This comparison provides an illustration of the general contribution of solvent cleaning and scraping, where joints fused with no cleaning or scraping consistently fall in the 0-20% ductility bin (as expected), joint fused with solvent cleaning alone fall in all ductility bins, and joints fused with only scraping predominantly fall in the top two ductility bins. This suggests that both solvent cleaning and scraping must be used to consistently achieve 100% ductility by using the solvent cleaning to remove loose dirt and then scraping to remove the outer layer of the pipe together with any contaminant that may be adhering to or embedded in it.

![Figure 22. Comparison of cleaning operations with bentonite contamination, overall decohesion results](image-url)
The findings in this project and OTD Project 2.14.e Guidelines/Best Practices for Scraping PE Pipe and Fittings lead to the suggestion of a preparation technique where the pipe is thoroughly washed and cleaned prior to scraping and where the time between scraping and assembling of the fitting is minimized. A proposed technique, which was also included in the final report of OTD Project 2.14.e, is detailed later in this section.

Overall, the various test results of this project and the results from OTD Project 2.14.e lend support to the observation that to achieve successful PE fusions best practices should be adopted in conjunction with thorough operator training with specific attention to prevention of contamination of the fusion areas of the pipe and fitting. The following are aspects that should be taken into account in operator training and reflected in operating procedures.

**Avoiding contamination of the fusion zone**

- Water wash any bulk and loose dirt and dust on the pipe prior to scraping.
  - The cleaned area should exceed the area to be scraped.
- Solvent-clean the assembly area immediately prior to scraping of the pipe.
  - The solvent cleaned area should be within the area cleaned with water.
  - Fitting’s fusion zone should also be solvent-cleaned immediately before assembly onto the pipe.
  - Allow solvent to fully dry before assembly.
- Minimize time between cleaning, scraping, assembling and fusing.
- Be aware that the scraping tool should be clean of contaminants before each use.
- Be aware that the scraping tool should be in proper working condition.
- Be aware that shavings from the scraping operation may wipe against a scraped surface, and thus may transfer contaminants onto it, if contaminants are present prior to scraping.
- Be aware that dirt, mud, water, and dust can resettle on the pipe during and after scraping due to one or a combination of:
  - Wind
  - Rain
  - Operator motion
  - Static charge on the pipe
- If the joining procedure must be delayed, apply stretch wrap to minimize contamination of the cleaned area.
- Smooth scraper blades may be preferable to serrated blades,
  - Serrated blades leave a rough surface that is harder to clean than a smooth surface.
  - Serrated blades are less consistent in terms of scrape depth and are more likely to leave portions of shallow scraping (ridges).
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 of utmost importance 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 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). Additionally, surface contamination affects PE fusion in the same way regardless of the joining method and joint geometry.

Suggested Scraping Procedure Guideline

Figure 23 shows a top-level generic scraping procedure guideline incorporating the lessons learned during this project, addressing contamination prevention in particular. The rationale behind this procedure is that all contamination will be removed prior to scraping and then minimizing the chances of the scraped pipe getting contaminated. The critical contamination avoidance aspects of the proposed procedure are (in chronological order):

5. Water-wash of pipe (exceeding the area to be scraped).

6. Solvent cleaning of the pipe with a specific wiping technique (exceeding area to be scraped, but within the water-washed area).

7. Scraping of the pipe immediately after solvent cleaning (within the solvent-cleaned area).

8. Assembly of the fitting and performing the fusion immediately after scraping.

Figure 24 and Figure 25 show schematics of the cleaned areas for saddle and coupling fittings, respectively.

For situations where a fitting cannot be fused immediately after scraping of the pipe, use of stretch wrap is suggested in this procedure. In such cases, stretch wrap can help minimize or eliminate recontamination of the area already scraped or cleaned.

For quality control (QC) purposes, this procedure also suggests that a wipe that was used to clean the pipe with solvent be kept in a plastic bag as it can be tested for contaminants.
Figure 23. Top-level generic scraping procedure incorporating best-practices
Figure 24. Schematic of cleaned areas for a saddle fitting

Figure 25. Schematic of cleaned areas for a coupling fitting
Potential Future Work

In light of the findings of this project, GTI suggested that additional testing be performed with a slight modification to the solvent cleaning and scraping technique, utilizing the remaining project budget. Project Sponsors approved this additional scope. This report will be amended with the results of the additional testing.

Another aspect of interest is to further explore solvent cleaning techniques and compare fusion ductility of joints fused after two or more wiping passes. Additional wiping passes may be rendered irrelevant by the results of the proposed scraping technique, however, it will still be applicable in cases where solvent cleaning is performed after scraping.

The commercially available handheld FTIR systems\(^2\) could be evaluated under a future project as a field QA/QC tool that can detect contamination and oxidation before and/or after scraping.

Appendix A – Pipe Contamination Apparatus

The pipe contamination apparatus was constructed in order to contaminate pipe in a consistent manner with a fine powder (talc, bentonite). The apparatus was built to meet the specifications given in the UK standard WIS-32-4-08 Specification for the Fusion Jointing of Polyethylene Pressure Pipeline Systems Using PE80 and PE100 Materials (see Figure 26).

![Figure A.1 Principle of screen apparatus for applying talc to pipe surface](image)

**Figure 26. Figure A.1 from WIS-32-4-08**

The apparatus has a computer controlled, electrically driven screen tray and a pneumatically actuated squeegee. Tray speed and movement distance are programmable, and squeegee force and manually adjustable via precision air pressure regulators. The pipe underneath the strainer is rotated synchronously with the motion of the tray. The apparatus is also adjustable to accommodate a range of pipe samples from 1/2” CTS to 8” IPS.

**Figure 27** through **Figure 30** show details of the pipe contamination apparatus.
Figure 27. Pipe contamination apparatus
Figure 28. View of motorized strainer carriage, squeegee lowered onto strainer
Figure 29. 2” IPS pipe sample in place for contamination
Figure 30. Pipe contaminator control console and electronics box
Appendix B – Post Decohesion FTIR Test Results

The following figures show the test results of the decohesion tests and FTIR data where applicable. Circles on photographs indicate the locations where FTIR readings were taken and they are color-coded to match the corresponding FTIR spectra figure. Taller contaminant peaks indicate less contaminant was removed.
**172318-001**

| 172318-001 | 172395-001 | Talc      | 99% Isopropanol | Lint-Free Wipe |

**Figure 31. Sample 172318-001, decohesion test result**

**Figure 32. Sample 172318-001, FTIR spectra from decohesion test result**
172318-002

| 172318-002 | 172395-002 | Talc | 99% Isopropanol | Cotton Cloth Rag |

Figure 33. Sample 172318-002, decohesion test result

Figure 34. Sample 172318-002, FTIR spectra from decohesion test result
**Figure 35.** Sample 172318-003, decohesion test result

**Figure 36.** Sample 172318-003, FTIR spectra from decohesion test result

<table>
<thead>
<tr>
<th>172318-003</th>
<th>172395-003</th>
<th>Talc</th>
<th>91% Isopropanol</th>
<th>Lint-Free Wipe</th>
</tr>
</thead>
</table>

Outer Cold Zone
Outer Fusion Zone
Mid Fusion Zone
Inner Fusion Zone
Inner Cold Zone

Talc peaks
Figure 37. Sample 172318-004, decohesion test result

Figure 38. Sample 172318-004, FTIR spectra from decohesion test result
Figure 39. Sample 172318-005, decohesion test result

Figure 40. Sample 172318-005, FTIR spectra from decohesion test result
Figure 41. Sample 172318-006, decohesion test result

Figure 42. Sample 172318-006, FTIR spectra from decohesion test result
Figure 43. Sample 172318-007, decohesion test result

Figure 44. Sample 172318-007, FTIR spectra from decohesion test result
Figure 45. Sample 172318-008, decohesion test result

Figure 46. Sample 172318-008, FTIR spectra from decohesion test result
### 172318-009

<table>
<thead>
<tr>
<th>172318-009</th>
<th>172395-009</th>
<th>Talc</th>
<th>91% Isopropanol</th>
<th>Paper Towel</th>
</tr>
</thead>
</table>

![Figure 47. Sample 172318-009, decohesion test result](image)

![Figure 48. Sample 172318-009, FTIR spectra from decohesion test result](image)
172318-010

| 172318-010 | 172395-010 | Talc | 91% Isopropanol | Paper Towel |

Figure 49. Sample 172318-010, decohesion test result

Figure 50. Sample 172318-010, FTIR spectra from decohesion test result
172318-011

| 172318-011 | 172395-013 | Talc       | 91% Isopropanol | Lint-Free Wipe |

Figure 51. Sample 172318-011, decohesion test result

Figure 52. Sample 172318-011, FTIR spectra from decohesion test result
Figure 53. Sample 172318-012, decohesion test result

Figure 54. Sample 172318-012, FTIR spectra from decohesion test result
Figure 55. Sample 172318-013, decohesion test result

Figure 56. Sample 172318-013, FTIR spectra from decohesion test result
**172318-014**

| 172318-014 | 172395-026 | Talc       | Acetone     | Lint-Free Wipe |

**Figure 57.** Sample 172318-014, decohesion test result

**Figure 58.** Sample 172318-014, FTIR spectra from decohesion test result
Figure 59. Sample 172318-015, decohesion test result

Figure 60. Sample 172318-015, FTIR spectra from decohesion test result
**172318-016**

| 172318-016 | 172395-030 | Talc | Acetone | Cotton Cloth Rag |

![Figure 61. Sample 172318-016, decohesion test result](image)

![Figure 62. Sample 172318-016, FTIR spectra from decohesion test result](image)

- Outer Cold Zone
- Outer Fusion Zone
- Mid Fusion Zone
- Inner Fusion Zone
- Inner Cold Zone

Talc peaks
**Figure 63. Sample 172318-017, decohesion test result**

**Figure 64. Sample 172318-017, FTIR spectra from decohesion test result**
172318-018

<table>
<thead>
<tr>
<th>172318-018</th>
<th>172395-034</th>
<th>Talc</th>
<th>Acetone</th>
<th>Paper Towel</th>
</tr>
</thead>
</table>

![Sample 172318-018, decohesion test result](image)

**Figure 65. Sample 172318-018, decohesion test result**

![FTIR spectra from decohesion test result](image)

**Figure 66. Sample 172318-018, FTIR spectra from decohesion test result**
172318-019

| 172318-019 | 172395-037 | Talc | None | None |

Figure 67. Sample 172318-019, decohesion test result

Figure 68. Sample 172318-019, FTIR spectra from decohesion test result
**Figure 69. Sample 172318-020, decohesion test result**

**Figure 70. Sample 172318-020, FTIR spectra from decohesion test result**
**Figure 71. Sample 172318-021, decohesion test result**

**Figure 72. Sample 172318-021, FTIR spectra from decohesion test result**
### Sample 172318-022

<table>
<thead>
<tr>
<th>Sample 172318-022</th>
<th>Sample 172395-042</th>
<th>Bentonite</th>
<th>99% Isopropanol</th>
<th>Lint-Free Wipe</th>
</tr>
</thead>
</table>

#### Figure 73. Sample 172318-022, decohesion test result

![Image of decohesion test result](image)

#### Figure 74. Sample 172318-022, FTIR spectra from decohesion test result

![Image of FTIR spectra](image)

- **Outer Cold Zone**
- **Inner Fusion Zone**
- **Inner Cold Zone**

Bentonite peaks
Figure 75. Sample 172318-023, decohesion test result

Figure 76. Sample 172318-023, FTIR spectra from decohesion test result
**172318-024**

| 172318-024 | 172395-046 | Bentonite | 99% Isopropanol | Cotton Cloth Rag |

**Figure 77.** Sample 172318-024, decohesion test result

**Figure 78.** Sample 172318-024, FTIR spectra from decohesion test result

- Outer Cold Zone
- Outer Fusion Zone
- Mid Fusion Zone
- Inner Fusion Zone
- Inner Cold Zone

Bentonite peaks
Figure 79. Sample 172318-025, decohesion test result

Figure 80. Sample 172318-025, FTIR spectra from decohesion test result
**172318-026**

<table>
<thead>
<tr>
<th>172318-026</th>
<th>172395-050</th>
<th>Bentonite</th>
<th>99% Isopropanol</th>
<th>Paper Towel</th>
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</thead>
</table>

![Figure 81. Sample 172318-026, decohesion test result](image)

**Figure 81. Sample 172318-026, decohesion test result**

![Figure 82. Sample 172318-026, FTIR spectra from decohesion test result](image)

**Figure 82. Sample 172318-026, FTIR spectra from decohesion test result**
172318-027

| 172318-027 | 172395-053 | Bentonite | 91% Isopropanol | Lint-Free Wipe |

Figure 83. Sample 172318-027, decohesion test result

Figure 84. Sample 172318-027, FTIR spectra from decohesion test result
Figure 85. Sample 172318-028, decohesion test result

Figure 86. Sample 172318-028, FTIR spectra from decohesion test result
**Figure 87.** Sample 172318-029, decohesion test result

**Figure 88.** Sample 172318-029, FTIR spectra from decohesion test result
### 172318-031

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>172318-031</td>
<td>172395-061</td>
</tr>
</tbody>
</table>

#### Figure 89. Sample 172318-031, decohesion test result

![Decohesion Test Result](image)

#### Figure 90. Sample 172318-031, FTIR spectra from decohesion test result

![FTIR Spectra](image)
Figure 91. Sample 172318-033, decohesion test result

Figure 92: Sample 172318-033, FTIR spectra from decohesion test result
172318-034

| 172318-034 | 172395-066 | Bentonite | Acetone | Lint-Free Wipe |

**Figure 93. Sample 172318-034, decohesion test result**

**Figure 94. Sample 172318-034, FTIR spectra from decohesion test result**
Figure 95. Sample 172318-035, decohesion test result

Figure 96. Sample 172318-035, FTIR spectra from decohesion test result
Figure 97. Sample 172318-036, decohesion test result

Figure 98. Sample 172318-036, FTIR spectra from decohesion test result
Figure 99. Sample 172318-037, decohesion test result

Figure 100. Sample 172318-037, FTIR spectra from decohesion test result
Figure 101. Sample 172318-038, decohesion test result

Figure 102. Sample 172318-038, FTIR spectra from decohesion test result
172318-039

| 172318-039 | 172395-077 | Bentonite | None | None |

Figure 103. Sample 172318-039, decohesion test result

Figure 104. Sample 172318-039, FTIR spectra from decohesion test result
172318-040

|          | 172318-040 | 172395-078 | Bentonite | None | None |

Figure 105. Sample 172318-040, decohesion test result

Figure 106. Sample 172318-040, FTIR spectra from decohesion test result
172318-041

| 172318-041 | 172395-081 | Silicon Grease | 99% Isopropanol | Lint-Free Wipe |

Figure 107. Sample 172318-041, decohesion test result

Figure 108. Sample 172318-041, FTIR spectra from decohesion test result
172318-042

172318-042 172395-082 Silicon Grease 99% Isopropanol Lint-Free Wipe

Figure 109. Sample 172318-042, decohesion test result

Figure 110. Sample 172318-042, FTIR spectra from decohesion test result
172318-042A

172318-042A  172395-082A  Silicon Grease  99% Isopropanol  Lint-Free Wipe

Figure 111. Sample 172318-042A, decohesion test result

Figure 112. Sample 172318-042A, FTIR spectra from decohesion test result
**172318-043**

<table>
<thead>
<tr>
<th></th>
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<th>Silicon Grease</th>
<th>99% Isopropanol</th>
<th>Cotton Cloth Rag</th>
</tr>
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</table>

**Figure 113. Sample 172318-043, decohesion test result**

**Figure 114. Sample 172318-043, FTIR spectra from decohesion test result**
172318-044

| 172318-044 | 172395-086 | Silicon Grease | Acetone | Lint-Free Wipe |

Figure 115. Sample 172318-044, decohesion test result

Figure 116. Sample 172318-044, FTIR spectra from decohesion test result
### 172318-045

<table>
<thead>
<tr>
<th>172318-045</th>
<th>172395-087</th>
<th>Silicon Grease</th>
<th>Acetone</th>
<th>Lint-Free Wipe</th>
</tr>
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</table>

#### Figure 117. Sample 172318-045, decohesion test result

[Image of decohesion test result]

#### Figure 118. Sample 172318-045, FTIR spectra from decohesion test result

[Image of FTIR spectra with labels: Inner Cold Zone, Inner Fusion Zone, Mid Fusion Zone, Outer Fusion Zone, Outer Cold Zone, Silicone peaks]
### 172318-046

<table>
<thead>
<tr>
<th>172318-046</th>
<th>172395-090</th>
<th>Silicon Grease</th>
<th>Acetone</th>
<th>Cotton Cloth Rag</th>
</tr>
</thead>
</table>

![Sample 172318-046, decohesion test result](image1)

**Figure 119. Sample 172318-046, decohesion test result**

![Sample 172318-046, FTIR spectra from decohesion test result](image2)

**Figure 120. Sample 172318-046, FTIR spectra from decohesion test result**

- Outer Cold Zone
- Outer Fusion Zone
- Mid Fusion Zone
- Inner Fusion Zone
- Inner Cold Zone

Silicone peaks
172318-047

| 172318-047 | 172395-091 | Silicon Grease | Acetone | Cotton Cloth Rag |

Figure 121. Sample 172318-047, decohesion test result

Figure 122. Sample 172318-047, FTIR spectra from decohesion test result
172318-048

| 172318-048 | 172395-094 | Silicon Grease | Acetone | Paper Towel |

Figure 123. Sample 172318-048, decohesion test result

![Image of decohesion test result]

Figure 124. Sample 172318-048, FTIR spectra from decohesion test result

![Image of FTIR spectra]

Silicone peaks

Outer Cold Zone
Outer Fusion Zone
Mid Fusion Zone
Inner Fusion Zone
Inner Cold Zone
**172318-049**

| 172318-049 | 172395-095 | Silicon Grease | Acetone | Paper Towel |

Figure 125. Sample 172318-049, decohesion test result

Figure 126. Sample 172318-049, FTIR spectra from decohesion test result
172318-050

Figure 127. Sample 172318-050, decohesion test result

Figure 128. Sample 172318-050, FTIR spectra from decohesion test result
172318-051

<table>
<thead>
<tr>
<th>Solvent Cleaning and PE Joining Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>172318-051</td>
</tr>
</tbody>
</table>

Figure 129. Sample 172318-051, decohesion test result

Figure 130. Sample 172318-051, FTIR spectra from decohesion test result

Silicone peaks
Figure 131. Sample 172318-052, decohesion test result

Figure 132. Sample 172318-052, FTIR spectra from decohesion test result
172318-053

| 172318-053 | 172395-105 | Silicon Grease | 91% Isopropanol | Lint-Free Wipe |

Figure 133. Sample 172318-053, decohesion test result

Figure 134. Sample 172318-053, FTIR spectra from decohesion test result

Silicone peaks
172318-054

| 172318-054 | 172395-106 | Silicon Grease | 91% Isopropanol | Lint-Free Wipe |

Figure 135. Sample 172318-054, decohesion test result

Figure 136. Sample 172318-054, FTIR spectra from decohesion test result
172318-055

| 172318-055 | 172395-109 | Silicon Grease | 91% Isopropanol | Cotton Cloth Rag |

Figure 137. Sample 172318-055, decohesion test result

Figure 138. Sample 172318-055, FTIR spectra from decohesion test result
Figure 139. Sample 172318-057, decohesion test result

Figure 140. Sample 172318-057, FTIR spectra from decohesion test result
172318-058

| 172318-058 | 172395-114 | Silicon Grease | 91% Isopropanol | Paper Towel |

Figure 141. Sample 172318-058, decohesion test result

Figure 142. Sample 172318-058, FTIR spectra from decohesion test result
**Figure 143.** Sample 172316-032, decohesion test result

**Figure 144.** Sample 172316-032, FTIR spectra from decohesion test result
Figure 145. Sample 172316-033, decohesion test result

Figure 146. Sample 172316-033, FTIR spectra from decohesion test result
Figure 147. Sample 172316-035, decohesion test result

Figure 148. Sample 172316-035, FTIR spectra from decohesion test result
172316-036

| 172316-036   | 172395-016 | Talc      | 99% Isopropanol | Cotton Cloth Rag |

Figure 149. Sample 172316-036, decohesion test result

Figure 150. Sample 172316-036, FTIR spectra from decohesion test result
Figure 151. Sample 172316-037, decohesion test result

Figure 152. Sample 172316-037, FTIR spectra from decohesion test result
172316-038

| 172316-038 | 172395-018 | Talc | 91% Isopropanol | Cotton Cloth Rag |

Figure 153. Sample 172316-038, decohesion test result

Figure 154. Sample 172316-038, FTIR spectra from decohesion test result
172316-041

| 172316-041 | 172395-021 | Talc  | 91% Isopropanol | Lint-Free Wipe |

Figure 155. Sample 172316-041, decohesion test result

Figure 156. Sample 172316-041, FTIR spectra from decohesion test result
Figure 157. Sample 172316-042, decohesion test result

Figure 158. Sample 172316-042, FTIR spectra from decohesion test result
**Figure 159. Sample 172316-044, decohesion test result**

**Figure 160. Sample 172316-044, FTIR spectra from decohesion test result**
Figure 161. Sample 172316-045, decohesion test result

Figure 162. Sample 172316-045, FTIR spectra from decohesion test result
Figure 163. Sample 172316-046, decohesion test result

Figure 164. Sample 172316-046, FTIR spectra from decohesion test result
Figure 165. Sample 172316-047, decohesion test result

Figure 166. Sample 172316-047, FTIR spectra from decohesion test result
Figure 167. Sample 172316-048, decohesion test result

Figure 168. Sample 172316-048, FTIR spectra from decohesion test result
Figure 169. Sample 172316-049, decohesion test result

Figure 170. Sample 172316-049, FTIR spectra from decohesion test result
Table 1: Comparison of Talc and None

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<thead>
<tr>
<th>Sample</th>
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<th>None</th>
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<tbody>
<tr>
<td>172316-050</td>
<td>Talc</td>
<td>None</td>
</tr>
<tr>
<td>172395-039</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Figure 171. Sample 172316-050, decohesion test result

Figure 172. Sample 172316-050, FTIR spectra from decohesion test result
### 172316-051

| 172316-051 | 172395-040 | Talc | None | None |

---

**Figure 173. Sample 172316-051, decohesion test result**

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**Figure 174. Sample 172316-051, FTIR spectra from decohesion test result**
Figure 175. Sample 172316-052, decohesion test result

Figure 176. Sample 172316-052, FTIR spectra from decohesion test result
Figure 177. Sample 172316-053, decohesion test result

Figure 178. Sample 172316-053, FTIR spectra from decohesion test result
Figure 179. Sample 172316-054, decohesion test result

Figure 180. Sample 172316-054, FTIR spectra from decohesion test result
172316-055

| 172316-055 | 172395-048 | Bentonite | 99% Isopropanol | Cotton Cloth Rag |

Figure 181. Sample 172316-055, decohesion test result

Figure 182. Sample 172316-055, FTIR spectra from decohesion test result
Figure 183. Sample 172316-057, decohesion test result

These FTIR samples were contaminated by silicone grease during handling, as can be seen from silicone grease peaks where bentonite peaks were expected.

Figure 184. Sample 172316-057, FTIR spectra from decohesion test result
172316-058

Figure 185. Sample 172316-058, decohesion test result

These FTIR samples were contaminated by silicone grease during handling, as can be seen from silicone grease peaks where bentonite peaks were expected.

Figure 186. Sample 172316-058, FTIR spectra from decohesion test result
**172316-059**

| 172316-059 | 172395-056 | Bentonite | 91% Isopropanol | Lint-Free Wipe |

This FTIR sample was contaminated by silicone grease during handling, as can be seen from silicone grease peaks where bentonite peaks were expected.

**Figure 187.** Sample 172316-059, decohesion test result

**Figure 188.** Sample 172316-059, FTIR spectra from decohesion test result
Figure 189. Sample 172316-060, decohesion test result

Figure 190. Sample 172316-060, FTIR spectra from decohesion test result
### Figure 191. Sample 172316-061, decohesion test result

### Figure 192. Sample 172316-061, FTIR spectra from decohesion test result
172316-063

| 172316-063 | 172395-064 | Bentonite | 91% Isopropanol | Paper Towel |

Figure 193. Sample 172316-063, decohesion test result

Figure 194. Sample 172316-063, FTIR spectra from decohesion test result
172316-064

| 172316-064 | 172395-067 | Bentonite | Acetone | Lint-Free Wipe |

Figure 195. Sample 172316-064, decohesion test result

This FTIR sample was contaminated by silicone grease during handling, as can be seen from silicone grease peaks where bentonite peaks were expected.

Figure 196. Sample 172316-064, FTIR spectra from decohesion test result
Figure 197. Sample 172316-065, decohesion test result

Figure 198. Sample 172316-065, FTIR spectra from decohesion test result
172316-066

| 172316-066 | 172395-071 | Bentonite | Acetone | Cotton Cloth Rag |

Figure 199. Sample 172316-066, decohesion test result

Figure 200. Sample 172316-066, FTIR spectra from decohesion test result
172316-067

| 172316-067 | 172395-072 | Bentonite | Acetone | Cotton Cloth Rag |

Figure 201. Sample 172316-067, decohesion test result

Figure 202. Sample 172316-067, FTIR spectra from decohesion test result
Figure 203. Sample 172316-068, decohesion test result

Figure 204. Sample 172316-068, FTIR spectra from decohesion test result
172316-069

<table>
<thead>
<tr>
<th>172316-069</th>
<th>172395-076</th>
<th>Bentonite</th>
<th>Acetone</th>
<th>Paper Towel</th>
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</table>

Figure 205. Sample 172316-069, decohesion test result

Figure 206. Sample 172316-069, FTIR spectra from decohesion test result
Figure 207. Sample 172316-070, decohesion test result

Figure 208. Sample 172316-070, FTIR spectra from decohesion test result
172316-071

<table>
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<th>Sample</th>
<th>172395-080</th>
<th>Bentonite</th>
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<th>None</th>
</tr>
</thead>
</table>

Figure 209. Sample 172316-071, decohesion test result

Figure 210. Sample 172316-071, FTIR spectra from decohesion test result
Figure 211. Sample 172316-072, decohesion test result

Figure 212. Sample 172316-072, FTIR spectra from decohesion test result
**Figure 213.** Sample 172316-073, decohesion test result

**Figure 214.** Sample 172316-073, FTIR spectra from decohesion test result
Figure 215. Sample 172316-074, decohesion test result

Figure 216. Sample 172316-074, FTIR spectra from decohesion test result
172316-075

| 172316-075 | 172395-089 | Silicon Grease | Acetone | Lint-Free Wipe |

Figure 217. Sample 172316-075, decohesion test result

Silicone peaks

Figure 218. Sample 172316-075, FTIR spectra from decohesion test result
Figure 219. Sample 172316-076, decohesion test result

Figure 220. Sample 172316-076, FTIR spectra from decohesion test result

| Solvent Cleaning and PE Joining Procedures | 172316-076 | 172395-092 | Silicon Grease | Acetone | Cotton Cloth Rag |

- Outer Cold Zone
- Outer Fusion Zone
- Mid Fusion Zone
- Inner Fusion Zone
- Inner Cold Zone

Silicone peaks
Figure 221. Sample 172316-077, decohesion test result

Figure 222. Sample 172316-077, FTIR spectra from decohesion test result
172316-078

| 172316-078 | 172395-096 | Silicon Grease | Acetone | Paper Towel |

Figure 223. Sample 172316-078, decohesion test result

![Image of decohesion test result with labeled zones]

Outer Cold Zone
Outer Fusion Zone
Mid Fusion Zone
Inner Fusion Zone
Inner Cold Zone

Silicone peaks

Figure 224. Sample 172316-078, FTIR spectra from decohesion test result
172316-079

<table>
<thead>
<tr>
<th>Material</th>
</tr>
</thead>
<tbody>
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<td>172316-079</td>
</tr>
<tr>
<td>172395-097</td>
</tr>
<tr>
<td>Silicon Grease</td>
</tr>
<tr>
<td>Acetone</td>
</tr>
<tr>
<td>Paper Towel</td>
</tr>
</tbody>
</table>

Figure 225. Sample 172316-079, decohesion test result

![Image of decohesion test result](image1)

Figure 226. Sample 172316-079, FTIR spectra from decohesion test result