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MV Cable Termination Failure Prevention

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How do we reduce the #1 cause of cable failures?

Workmanship

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Agenda

- Review of initial research
- Breakdown of workmanship issues
- Types of workmanship issues
- Causes of workmanship issues
- What can we do to avoid these problems?
- What did we learn?

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EA Technology Group

- Originally established as R&D Center for the UK Electricity Industry. Privatized in the early 1990s.
- Provides research, strategic engineering consultancy, HV asset condition assessment services, specialized instrumentation and asset management software and consulting.
- Discovered the TEV effect in 1978 and developed the first practical detection method in 1982
- Instrumental in the development of PAS-55 and ISO-55000
- Maintains a large forensic investigation lab equipped with the latest technology and staffed by highly experienced scientists.

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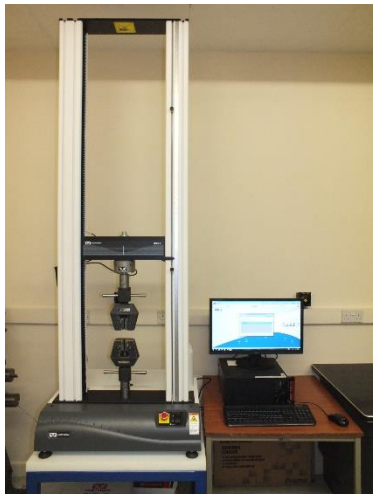
What is a Forensic Investigation?

"Collecting and analyzing data in order to draw scientific conclusions about failure mechanisms, causes and remediation"



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Our Research Procedure

Reports pulled from 2011-2015 from EA Technology's Forensic Analysis Reports

100 Reports Reviewed

- 27 Deemed Irrelevant and Discarded from Study
  - Lower Voltage Class
  - No Failure Occurred
  - Mechanical Failure, Not Electrical
- Remaining 73 Reports Analyzed

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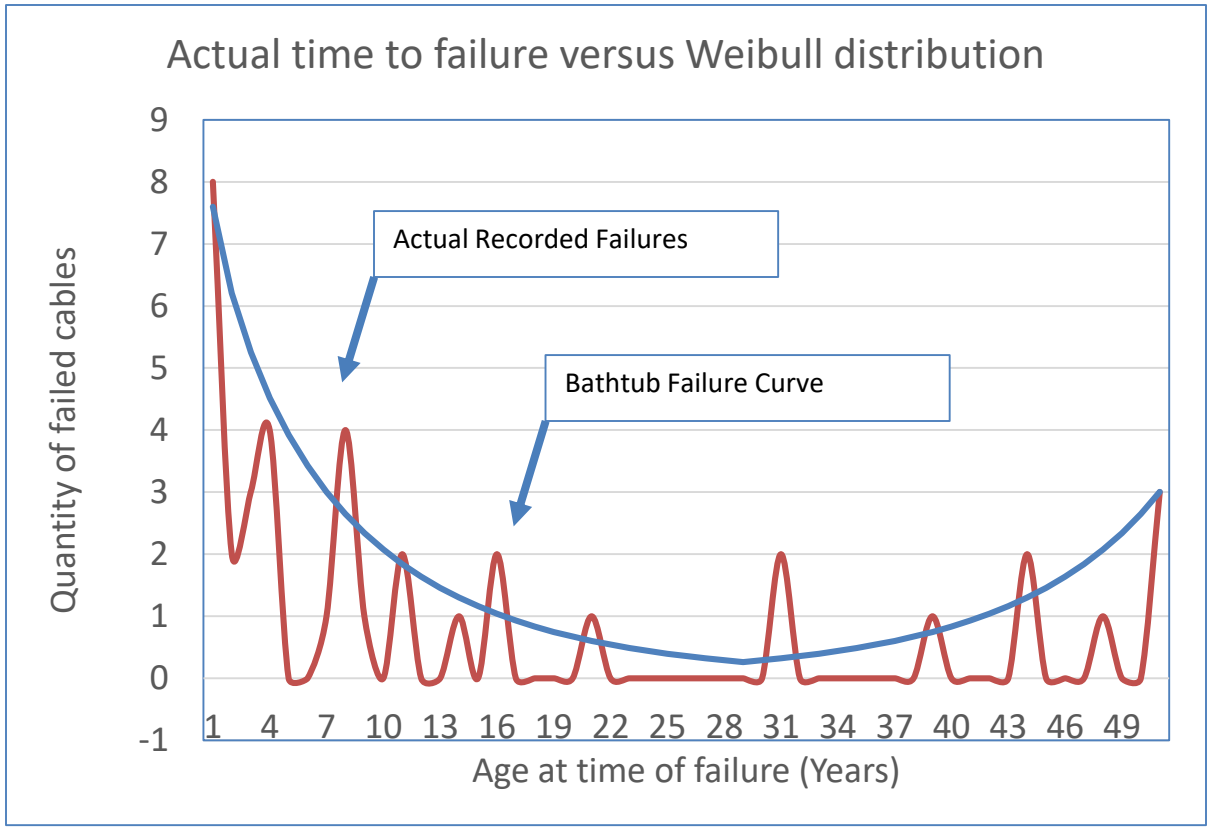
Study Results – Failures over time



- Typical bathtub curve failure pattern
- Indicates failure rates are predictable.

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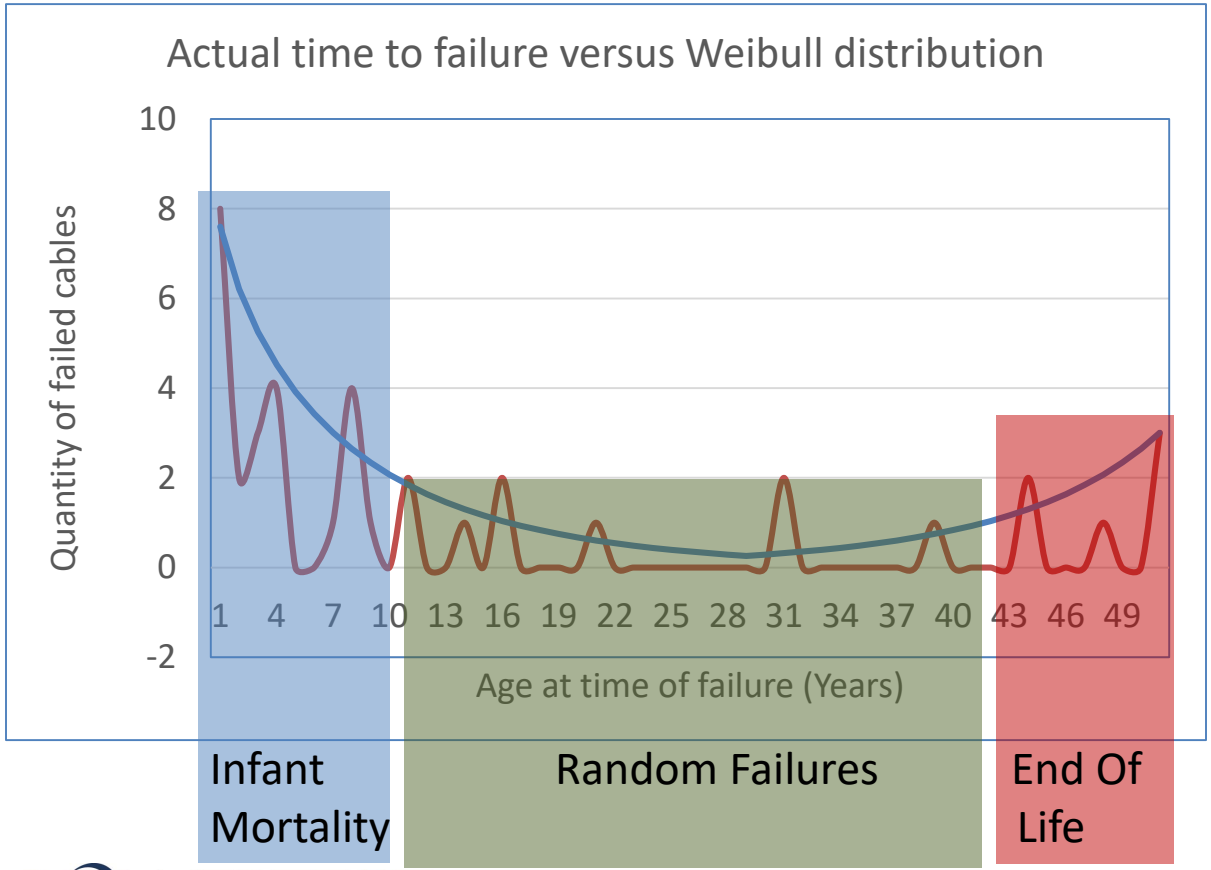
Study Results – Cable Life Stages (IM, RF, EOL)



- Infant Mortality (IM) period is ~ 10 years
- Infant Mortality makes up largest segment
- Random Failure (RF) Period from 10 to 40 years of age
- After 40, End of Life (EOL) begins

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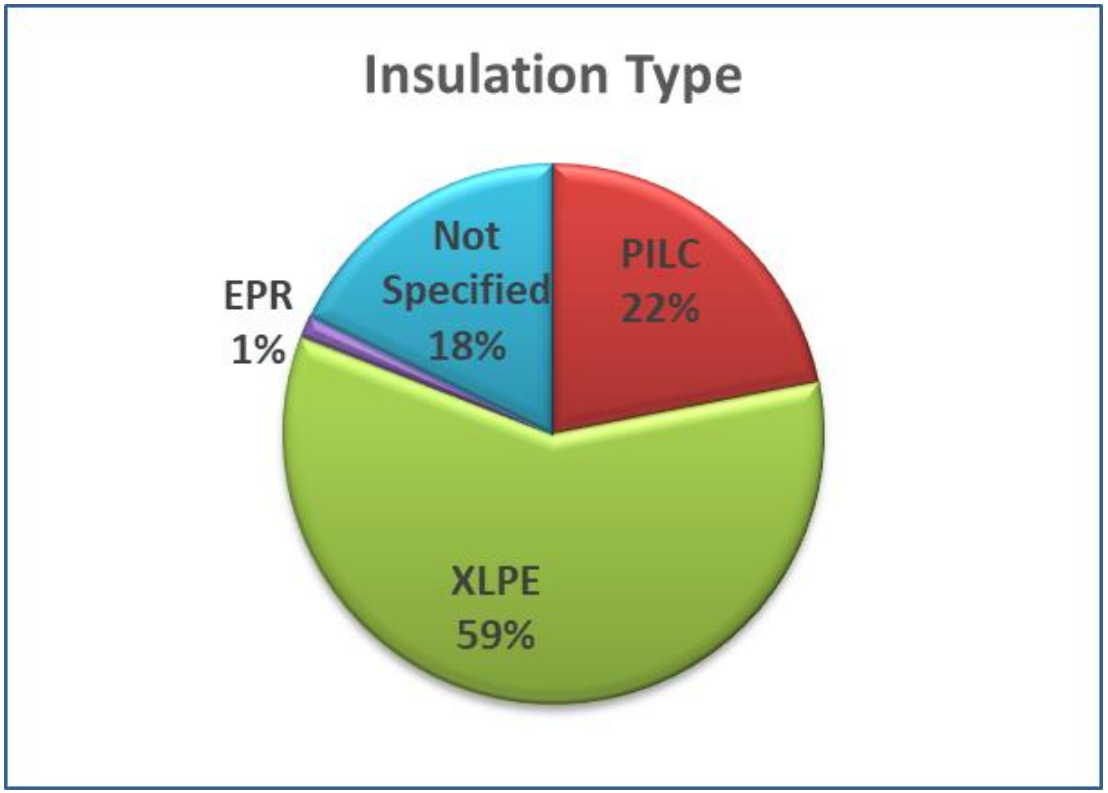
Study Results – Failures versus cable type



- XLPE makes up >70% of those identified
- XLPE and PILC show similar ratio of failures per mile of installed base*
- EPR shows disproportionally fewer failures per mile

*Installed base ratios estimated from "Historical Overview of Medium & High Voltage Cables", N Hampton GATECH NEETRAC

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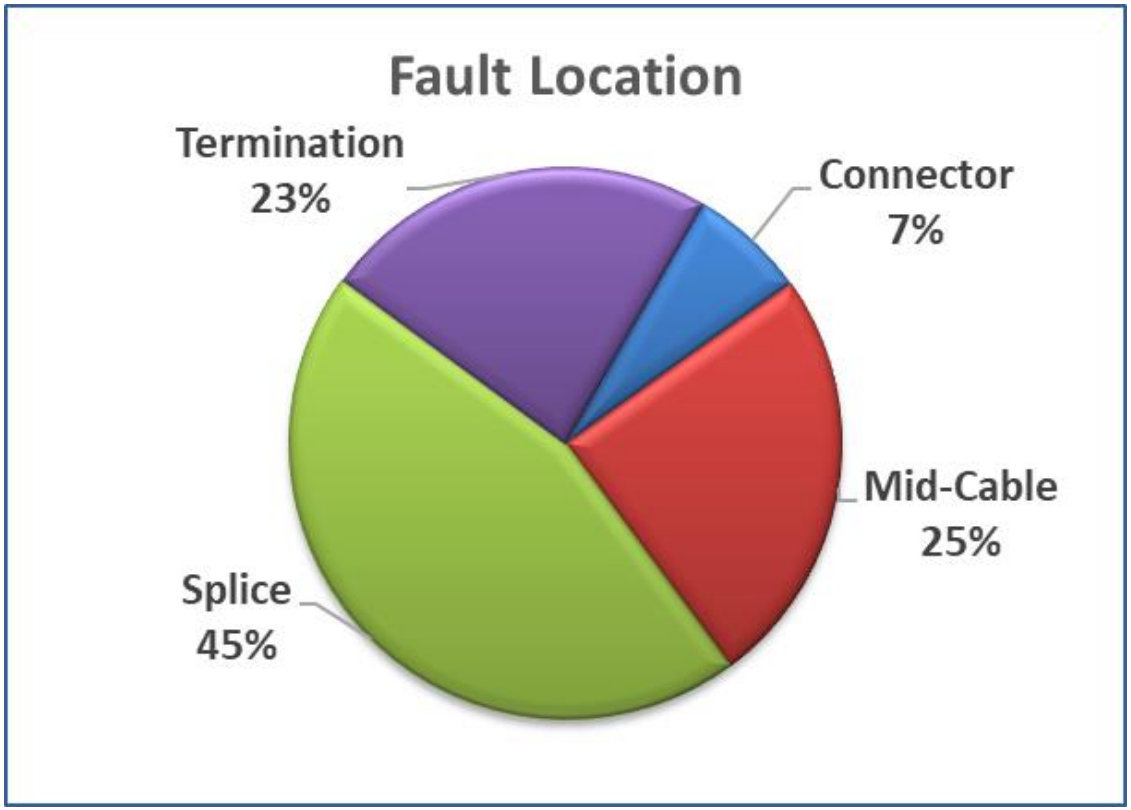
Study Results – Failure locations



- Places where technicians work on cable in field make up 68% of failures
- Mid-Cable failures could be
  - Mechanical
  - Application
  - Manufacturing
  - Random

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Study – What is a "cause"?

The Titanic sank……Why?

1. The boat filled with water – Natural effect
2. There was a hole in the boat – Proximate Cause
3. The boat hit an iceberg
4. The boat was going too fast
5. White Star Lines was showing off – Ultimate Cause

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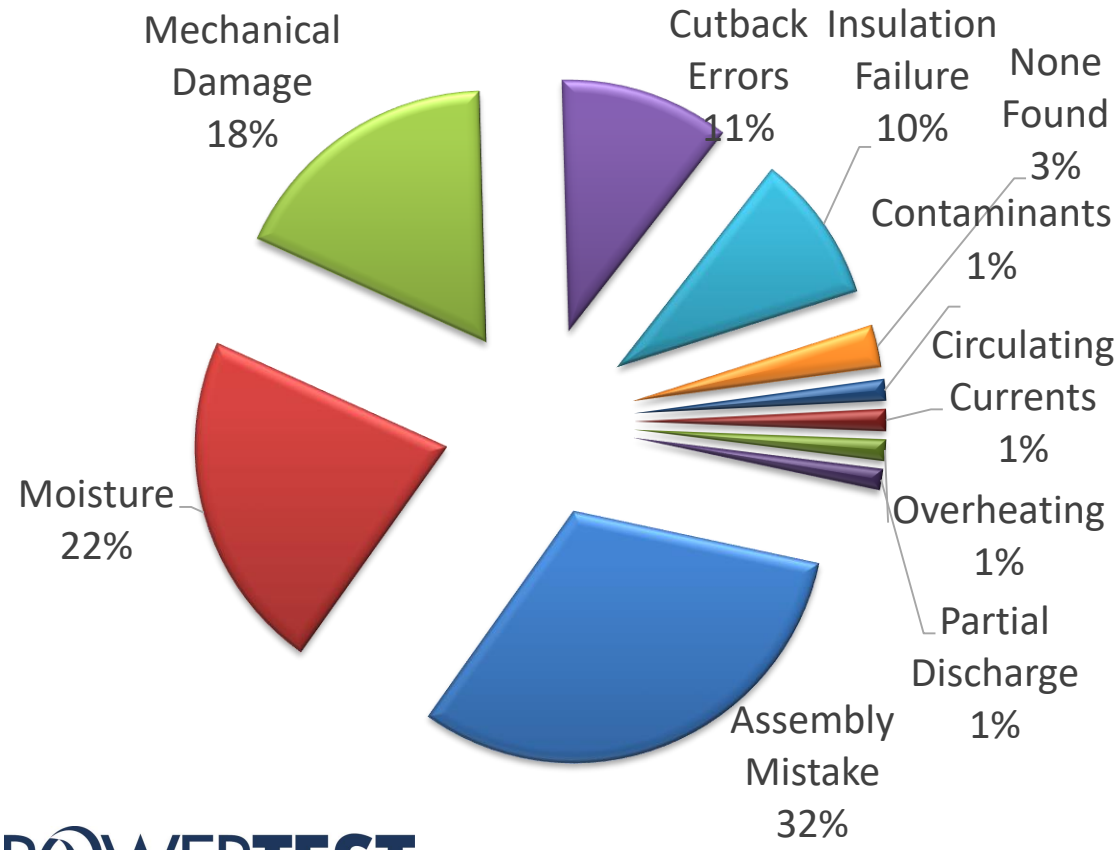
Study Results – Proximate Causes



- Assembly Mistakes appear to cause 1/3 of Failures
- "None Found" is very small percentage of cases
- Clearly Proximate Cause is not good for seeing whole picture
  - Why are there so many moisture failures?
  - What is causing mechanical damage?

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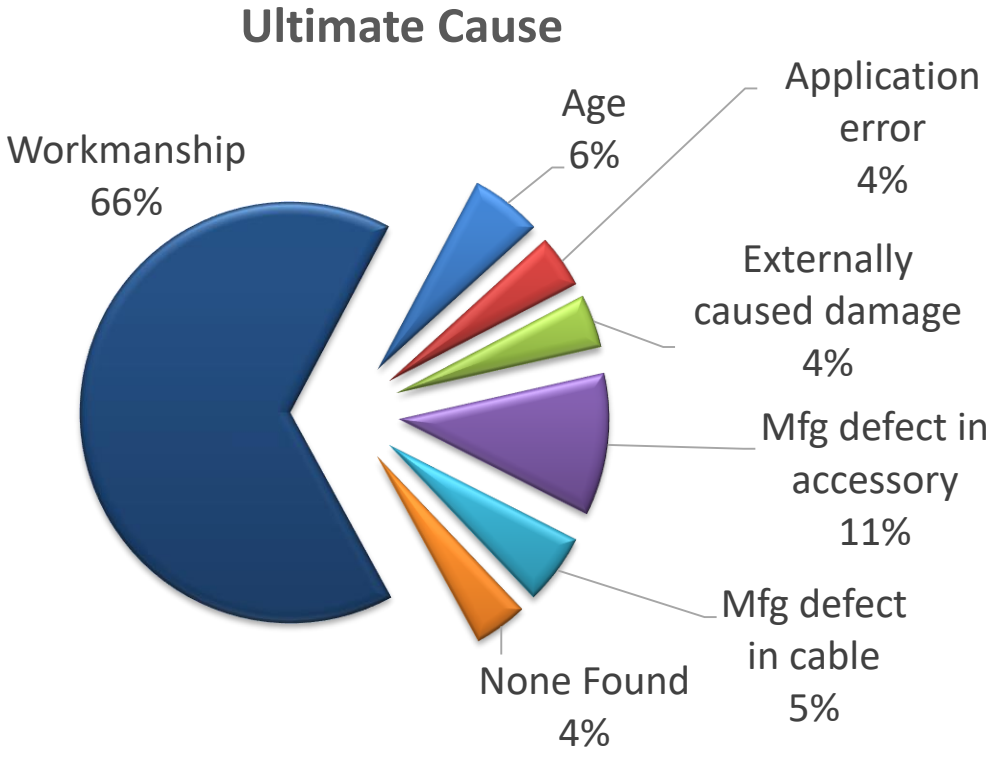
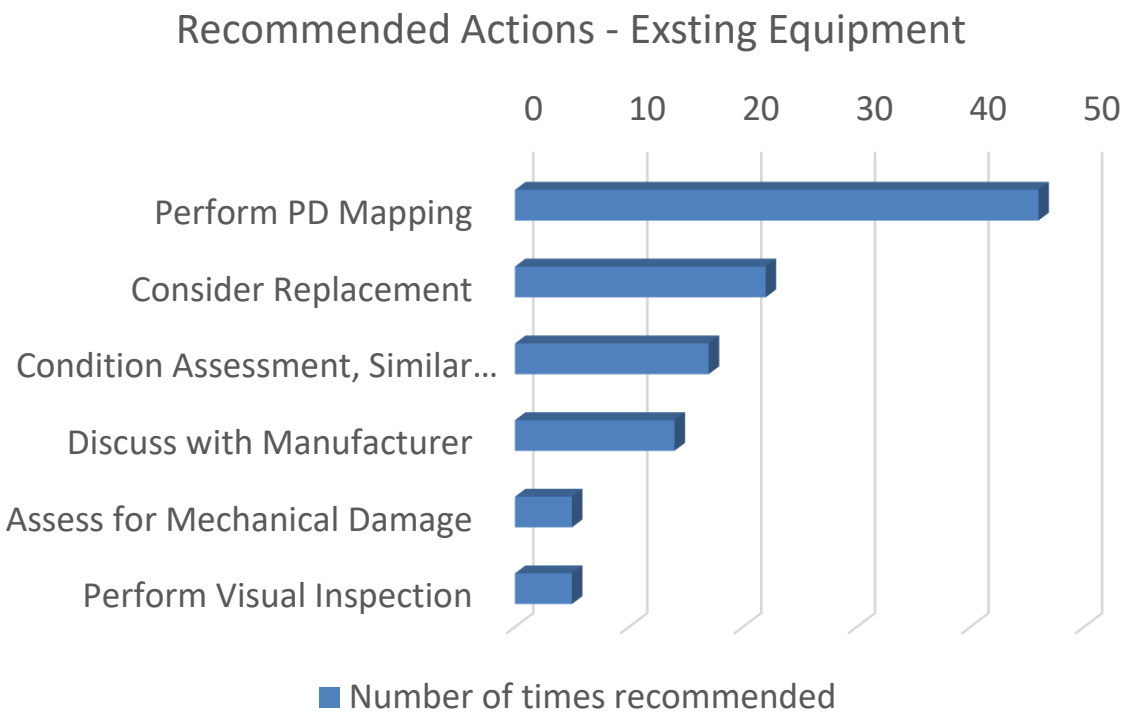
Study Results – Ultimate Causes



- Ultimate Cause paints a very different picture
- Workmanship is 2/3 of all failures
- Manufacturers defects are not insignificant (16%)
- External damage is not a big contributor
- Age related failures are small

Study Results – Recommended action to prevent failures in existing equipment



- PD mapping is highly recommended
- Replacement is one of the only other choices
- Visual Inspection is of limited value as most problems are hidden
- Manufacturer may be able to offer advice

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Analyzed the 44 failures that were caused by workmanship issues

- Identified the errors
- Categorized the errors
- Tabulated and analyzed the most common

Who can guess the most common issue?

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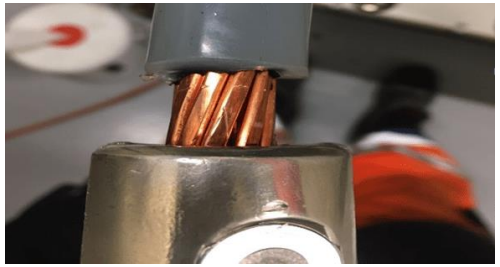
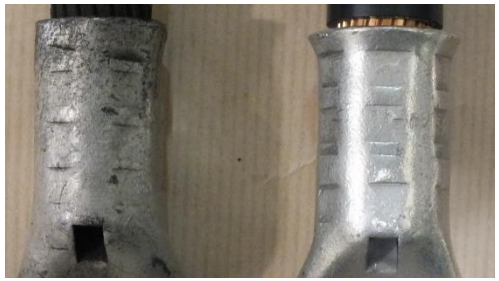
Semi-con Removal Errors?

Misplaced Tape?

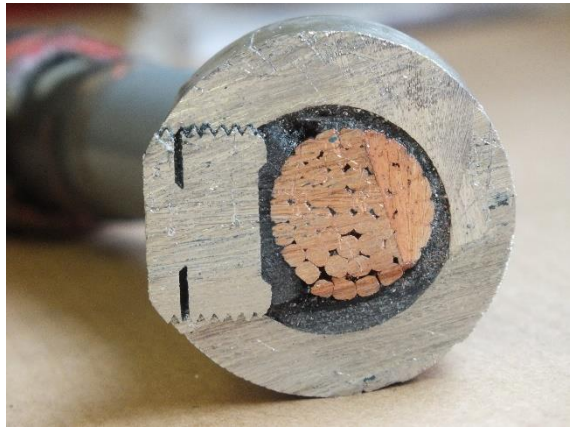


Gaps and voids?

Shear Bolt Burrs?



Crimping Errors?



Unbelievable Errors?

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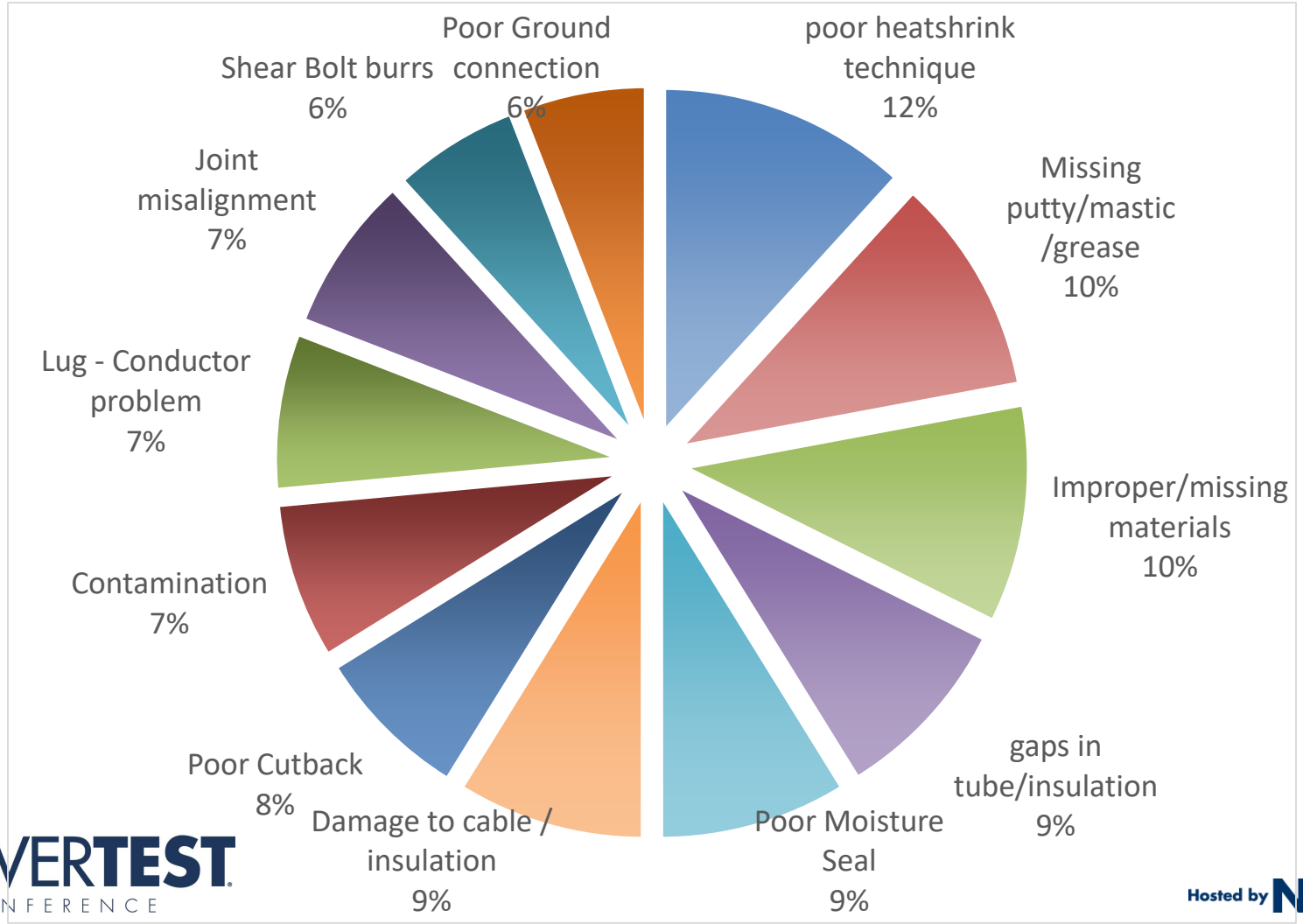

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Vague Instructions

These are actual quotes from termination instructions

“Note: Do not nick the insulation”
“Prepare cable as usual”
“Clean Cable Insulation and Lug or Connector Barrel Using Standard Practice”

These statements mean different things to persons with different levels of training and experience.

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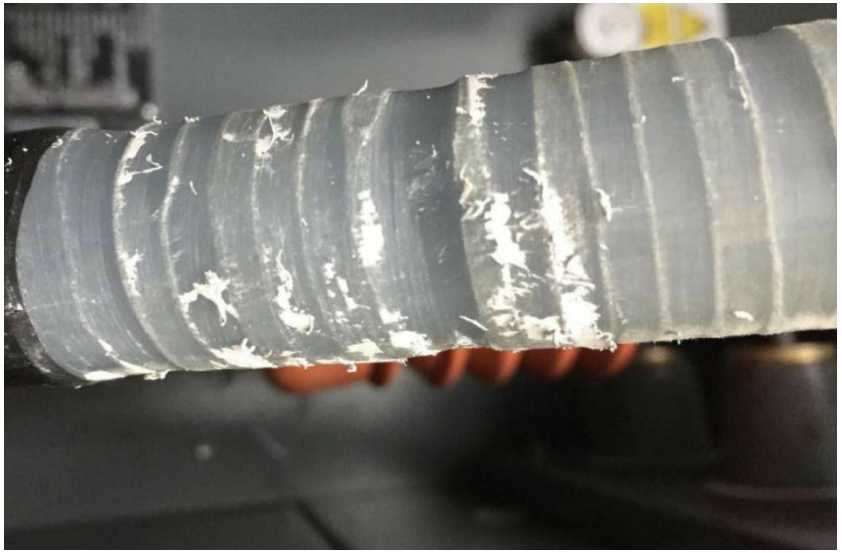
Vague Instructions

Most cable termination instructions make a point of saying “**with no remaining conductive material”** when discussing screen removal.



Both of these cables meet that criteria!

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Tools - What tools are appropriate?

Most instructions don't call out what tools should be used.

If a jointer is not skilled in knife work, it is next to impossible to get a good joint

Tools

Open knives are banned in the UK for safety reasons
HV (66 KV and higher) - most use specialized tools
MV – varies with industry. Several still using knives in North America.
Hard to get people to change their ways

Hacksaws and glass shards still common in some parts of the world.

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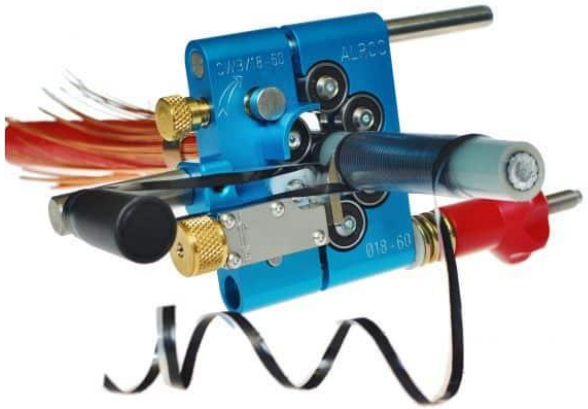
Tools

Numerous specialized tools exist for:

- Stripping sheath
- Removing bonded screens
- Removing strippable screens
- Chamfering insulation



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Cleanliness – How clean is clean enough?

Keeping a joint clean, especially a buried joint, is hard

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Cleanliness – How clean is clean enough?

We want this level of clean

under these conditions

Spend the time to prepare a clean work area (plastic or tarps, shelter)

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Lug Attachment - This should be easy!

Shear bolt lugs and tools

Crimp lugs, tools, and dies

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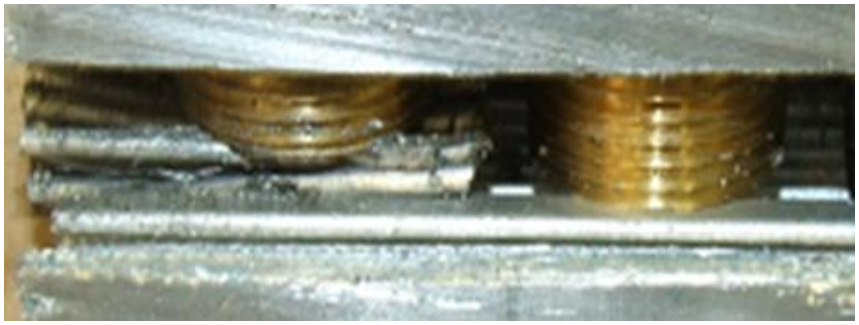
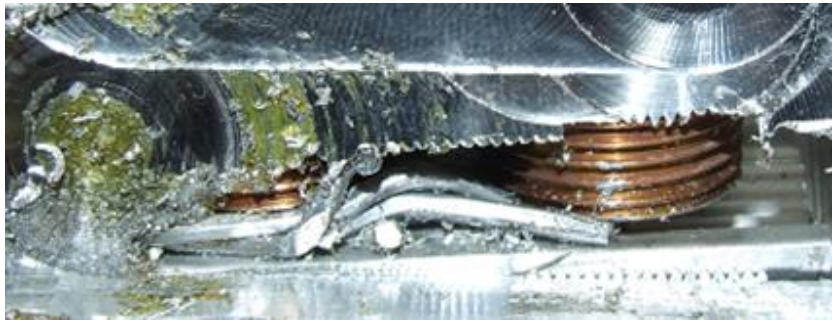
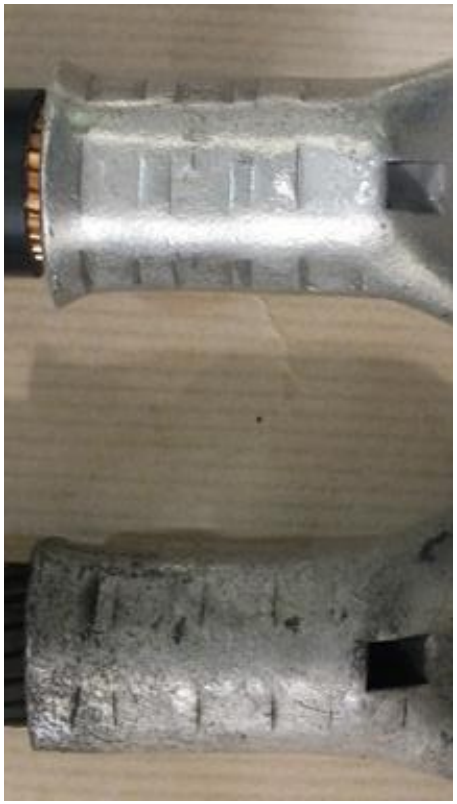
Lug Attachment - This should be easy?







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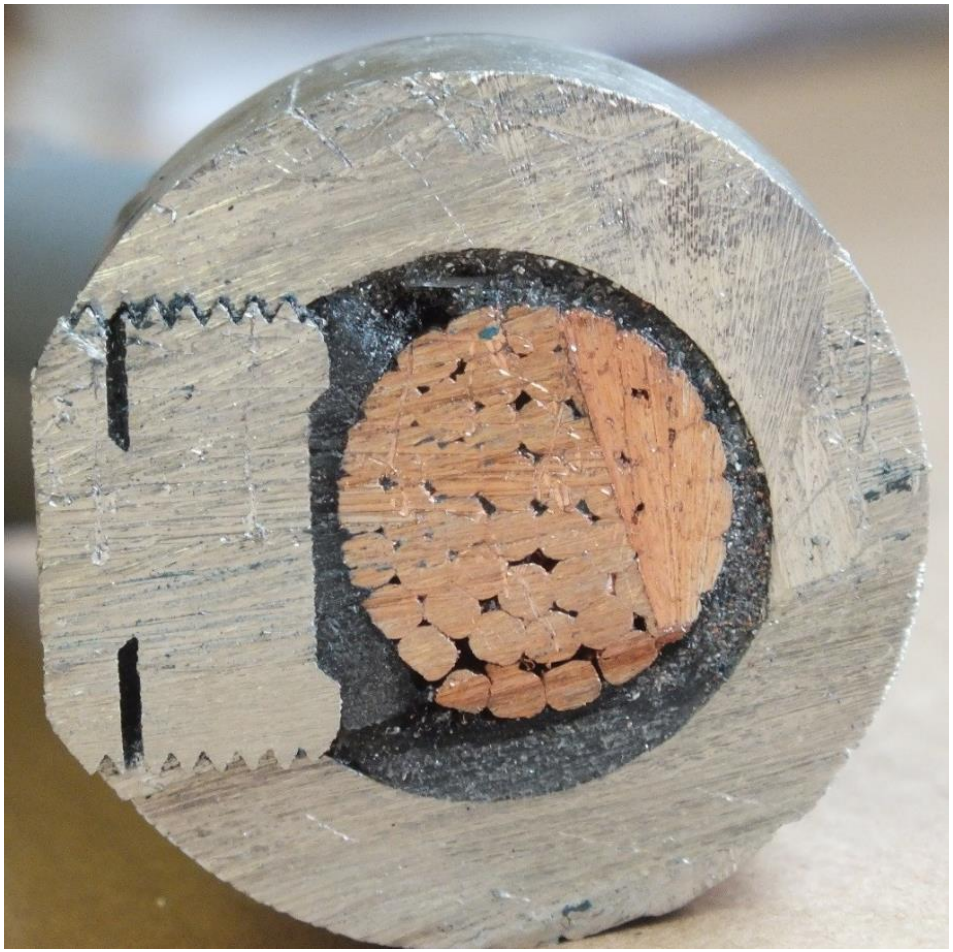

Easy?

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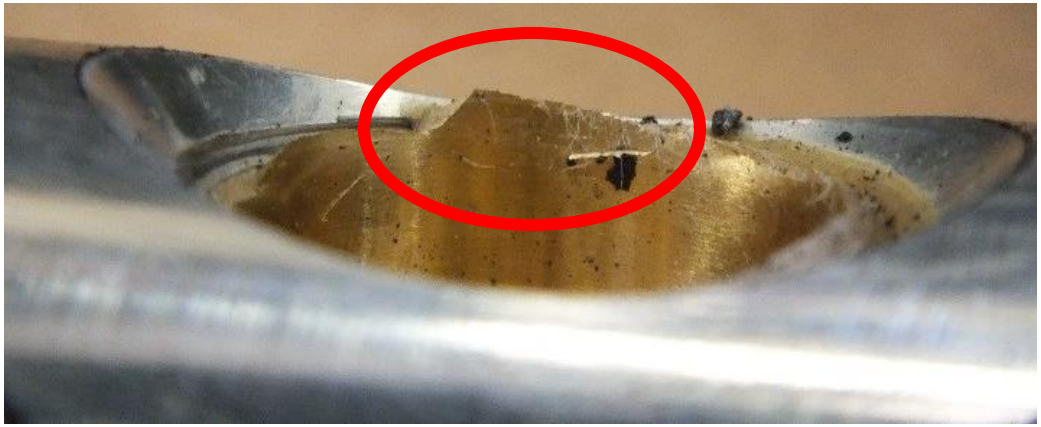
Shear bolt burrs

All instructions tell the user to deburr the bolts after shearing but lots of people neglect this step



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Mastic, Putty & Grease

Flexible materials allow a lot of room for error. How much, where, too much? What is this for? Stretch, don't stretch too much.

The more room you leave for ambiguity, the more problems you will have.

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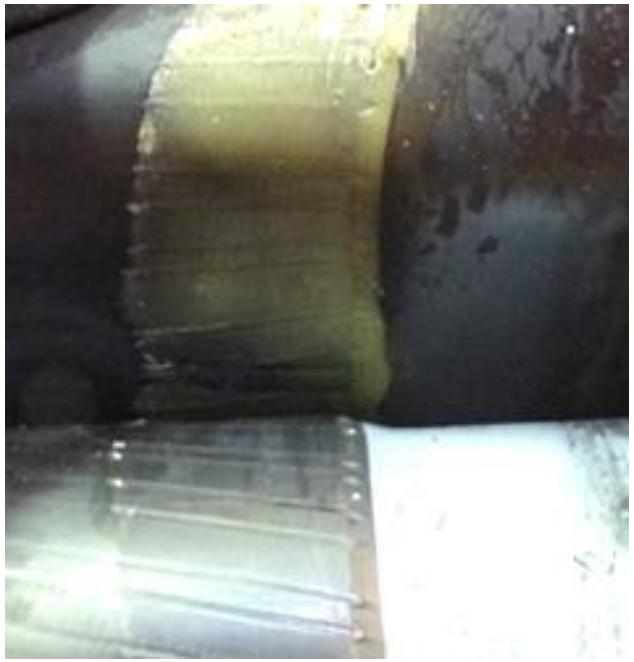
Mastic, Putty & Grease



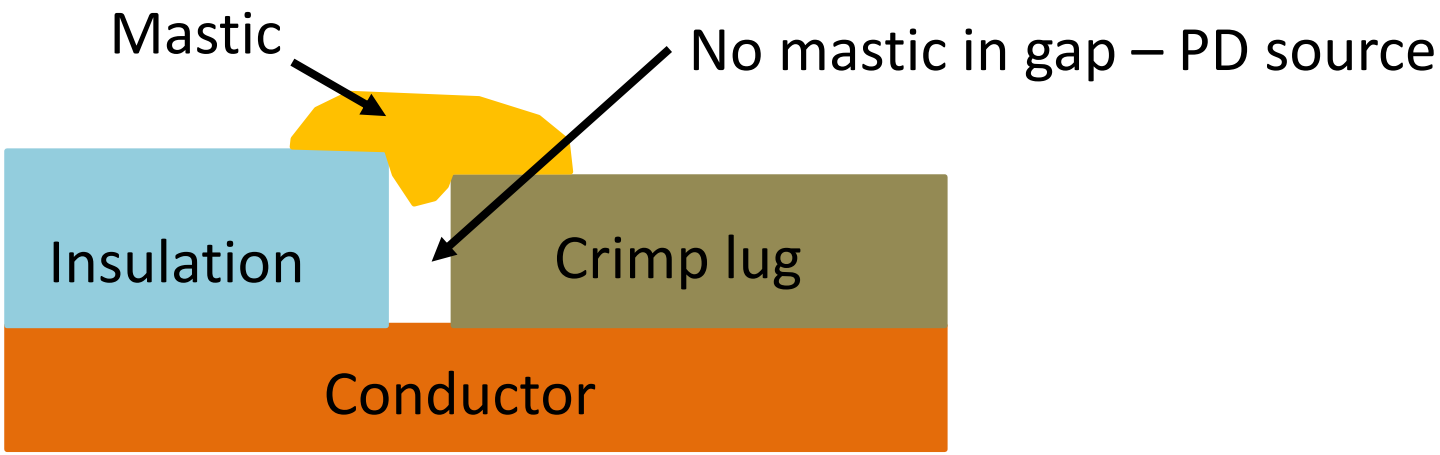
Mastic not lined up properly

No mastic in gap

No putty at all

1 out of every 10 failures was caused by poor putty/mastic placement

Mastic, Putty & Grease



Jointers need to understand that voids lead to failure

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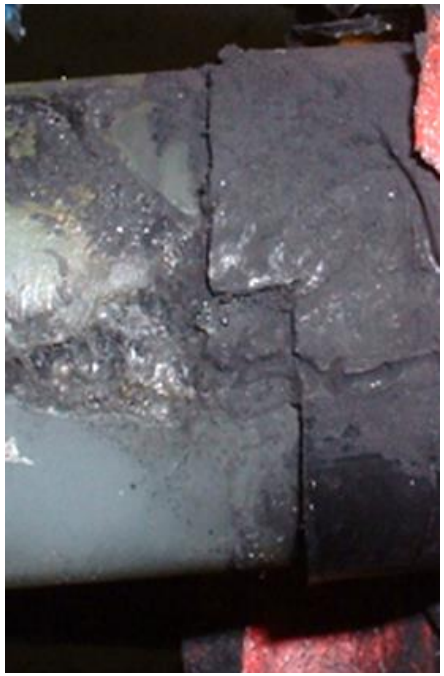
Semi-Conductor Cut Back Errors



Note – if you use the rattail file method, make sure your termination kit doesn't need a square edge.

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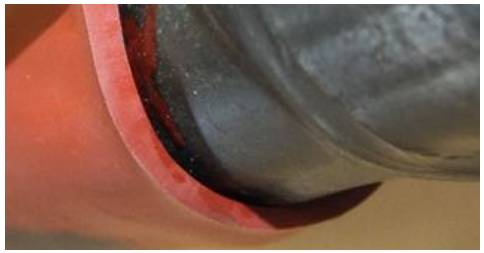
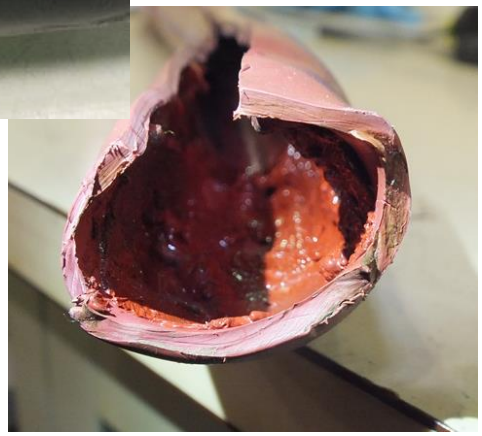
Heat shrinking errors – the #1 cause of cable failures

Poor heat shrinking leads to thin spots, voids, PD, or moisture and dirt ingress.





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Anecdotal comments - from US, Canada, and UK

UK – Poor semi-con cutbacks are the #1 problem

US – Lack of skilled jointers leads to non-experts making joints

Canada – Lack of skilled workers and time pressures

US – Advent of cold shrink kits made everyone an expert

UK – Even with proper tools, semi-con layer can be a problem

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So, how do we prevent this?

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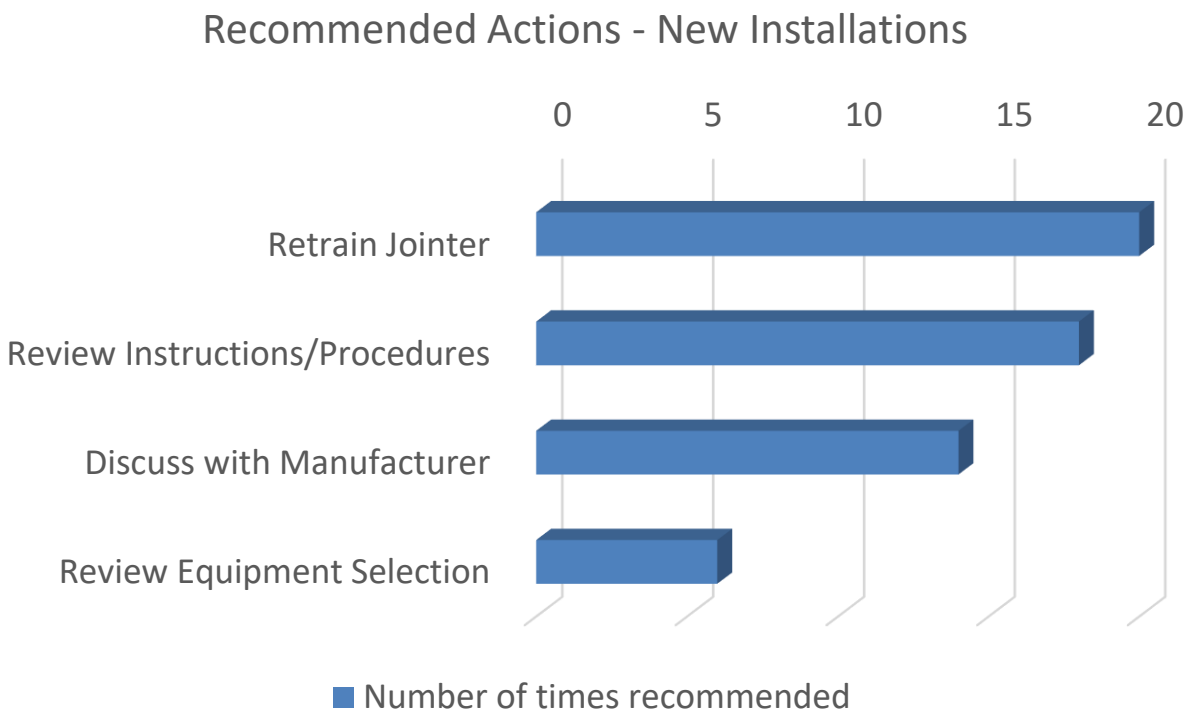
Study Results – Recommended Action to Prevent Failures in Future Installations



- Jointer training is key
- Review the instructions and talking to the manufacturer where unclear can be hugely helpful
- Make sure you are using the right parts for the job

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Study Results – Recommended Action to Prevent Failures in Future Installations

1) Best Possible Training
2) Clear, Concise Instructions
3) Proper Tools
4) Proper Application
   - Right parts for the job
   - Easiest to use parts for the job

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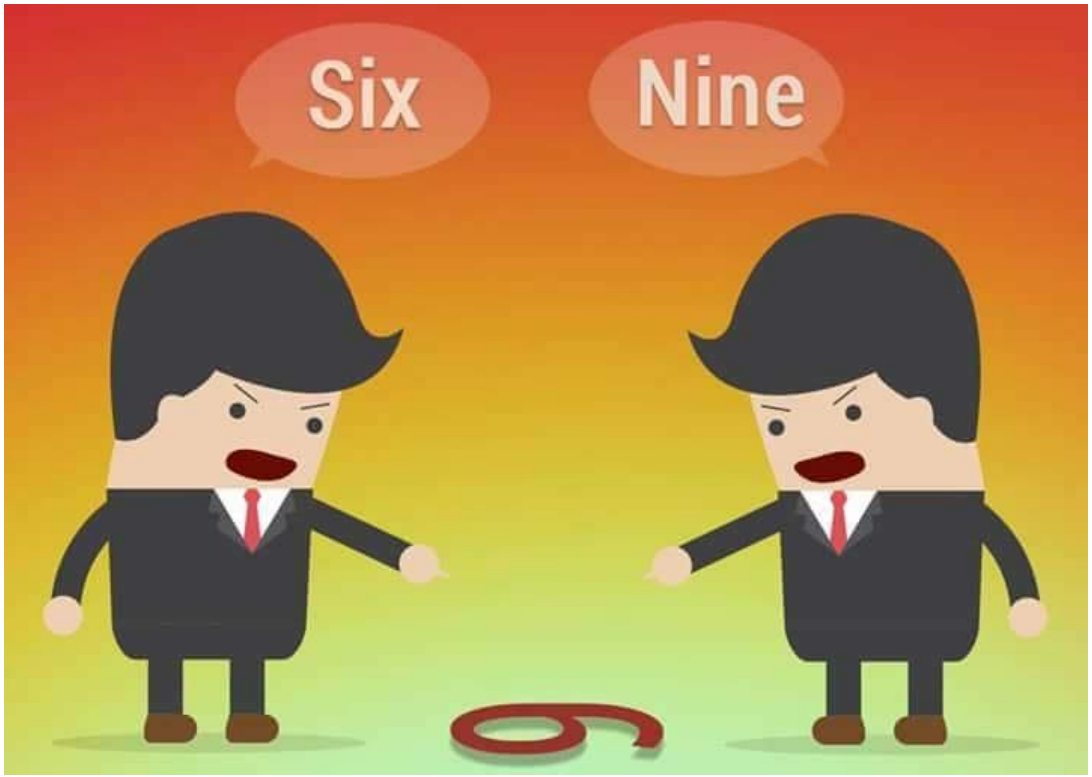
In life, experience, role, and training determine perspective



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Training – Understanding of wording is highly influenced by experience.

This guy from South Africa was ordering his first taco ever:

Customer – ”I want a taco”
Worker – “Take a napkin too”
Customer – “Why do I need a napkin?”
Worker – “If you’ve never had a taco, you are going to have a mess all over your pants if you don’t take a napkin. Maybe your shirt too“
Customer – “Never mind, I don’t want a taco that bad”

In South Africa, what we call a napkin, they call a serviet. What they call a napkin, we call a diaper.

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Training – An Exercise

1. Verbally tell a non-technical person how to perform a task in which they have no experience
2. Watch in **horror** as they perform the task
3. Revise your training until they do it right

The number one mistake is expecting that students hear what you mean. Actually, students perceive what they think you say.

My wife said
"butter the toast"

What she meant

What I did

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Training – Tips for successful training

1. Visual aids – If a picture is worth a thousand words, a physical sample is worth a million.
2. Provide short videos for reference at any time
3. Use pictures of bad and good so they can see what good means
4. Hands on training – let them fail!
5. Proof of success / failure – energize the sample and test it.
6. Continuous improvement – get feedback and improve the training
7. Skills degrade - Retrain out bad practices

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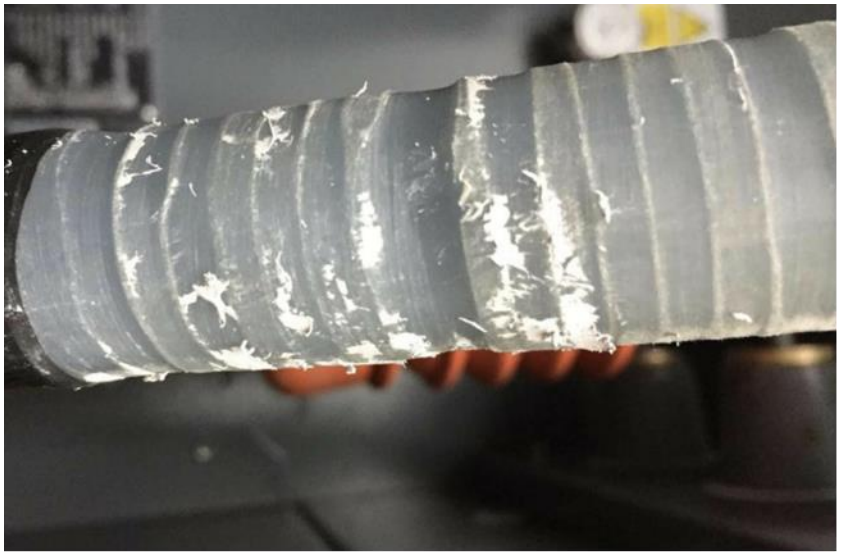
Better Instructions

Don’t say:
“Make sure insulation surface is clean and free of semi-con”



Well, it is free of semicon.

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Better Instructions

Say Instead:

- Use tool xxx to remove screen without damage to insulation.
- Adjust tool in accordance with operating practice yyy
- Confirm tool setting on cable waste section
- Insulation must be smooth and clean - see image zzz
- Screen edge must be flat and sharp – see image aaa
- Screen edge must not have any protrusions – see image bbb
- Insulation must not have knife nicks – see image ccc
- Smooth insulation using 220 grit emery cloth
- Clean insulation with ddd and wipes, wipe toward screen

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Talk to the Manufacturers

Make sure:

- The materials supplied meet the application
- The right tools are used
- That you understand the instructions implicitly
- You use that in training the jointers

The manufacturers really want you to succeed with every joint. They can be your best resource

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What Did We Learn Today?

- Forensic investigations tell us jointer errors are leading cause of cable failures
- Workmanship issues can take a wide variety of forms
- Investment in the right tools improves quality and safety
- Training is imperative to prevent failures
- Make sure your training is effective from the student's perspective

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Disclaimer – This study involved a modest number of samples over a relatively short period of time. While the authors believe the results to be representative of actual field conditions. This cannot be guaranteed. Sample size, time period, motivations for investigations, etc. could contribute to variations from a more detailed study.

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Please Remember to Complete Your Evaluation Form

Thank You!