Thermal Considerations of Composite Repairs

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Introduction

• As an industry, composites repairs are constantly breaking new ground
• Repairs on non-ambient piping systems are becoming very common
• However, there are many considerations that initially may not be taken into account and may not be obvious
Glass Transition Temperature (Tg)

• Surpassing Tg reduces mechanical values
• ASME PCC-2 uses Tg as temperature limits

  • Leaking Repairs
    \[ T_m = T_g - 54^\circ F \]

  • Non-Leaking Repairs
    \[ T_m = T_g - 36^\circ F \]
Effects on Mechanical Properties

- **Tg Zone**
  - Tg is not a specific value, it refers to range around the value stated
- **Storage Modulus (green line)**
  - As temperature increases consistent decrease in storage modulus can be seen.
  - At the Tg zone, modulus decreases
Cure Profile Effects on Tg

Maximum Tg will only be slightly above cure temperature

- Cure Temp: 160°C, Tg ≈ 175°C
- Cure Temp: 100°C, Tg ≈ 120°C
Effects on Mechanical Properties

- With any temperature increase, mechanical properties, such as tensile strength, decrease
- This decrease in strength should be considered for any high temperature repairs
Importance of Testing

• Every system reacts differently to temperature
• It is important to test every component of a system at temperature to determine any potential limitations
Application Temperature

• The environmental or pipe temperature can affect several application conditions:
  • Proper resin mixing
  • Working time
  • Set time
  • Viscosity

• Ensure application temperatures have been considered for pipe temperatures:
  • Below ≈ 60°F
  • Above ≈ 100°F,
Ambient Conditions

- Cold ambient conditions can:
  - Increase viscosity
  - Difficult to mix resins and wet-out fabric

- Hot ambient conditions can:
  - Decrease working time
Hot Pipes - Reduced Viscosity

- All wet resin material undergo changes in viscosity due to temperature
  - composite, adhesive, filler etc...

- Reduction in viscosity can liquefy resin:
  - Filler material not able to reshape pipe
  - Adhesive is too thin and runs off pipe
  - Wet resin runs from fabric
Hot Pipes - Reduced Set Time

• Increasing temperature accelerates reactions
• Materials may set too quickly (within minutes)
  • Filler material
    • May set before reshaping is complete
  • Adhesive
    • Sets before wrapping can begin
• Composite Wrap
  • Inner layers set before de-bulking
Cold Pipes

• Temperature effects set time of polymers
  • Ex:
    At 80°F: Resin A sets in 2 hours
    At 30°F: Resin A sets in 3 days
    At -10°F: Resin A sets in 6 weeks

• Cure time is typically 10x longer!
Thermal Expansion

• Coefficient of Thermal Expansion (CTE): Used to determine amount of expansion due to difference in temperature

• Most materials expand when heated and shrink when cooled

• Materials have different CTEs
  • Needs to be considered when large temperature differences are expected
Thermal Expansion

• Thermal Expansion in the hoop direction can be a concern with:

  • Hot pipes
    Ambient installation temperature
    High operational temperature

  • Pipes with temperature spikes
    Installed at warm temperatures
    Experiences high temperature conditions

• Need to consider “Design Temperatures” over lifetime of repair - not current operating conditions
Thermal Expansion
Fiberglass

- When heated:
  - Pipe expands
  - Fiberglass expands MORE

- Effects:
  - Repair separates from pipe
  - Strains adhesive
When heated:

- Pipe expands
- Carbon Fiber expands LESS

Effects:

- Repair compresses pipe
- Engaged repair
Thermal Contraction

- Thermal Contraction in the hoop direction can be a concern when:
  - Cold pipes:
    Ambient installation temperature
    Sub-zero operational temperature
    ex: Liquid Nitrogen line
  - Installation performed at high temperature and then pipe is temporarily out of service
Thermal Contraction
Fiberglass

• When cooled:
  • Pipe shrinks
  • Fiberglass shrinks MORE

• Effects:
  • Repair compresses pipe
  • Engaged repair
Thermal Contraction

Carbon Fiber

• When cooled:
  • Pipe shrinks
  • Carbon Fiber shrinks LESS

• Effects:
  • Repair separates from pipe
  • Strains adhesive
Axial Thermal Contraction

- Thermal contractions can be a significant source of failure in weakened girth welds
- As the pipe segments contract, they create stress in the weld
Axial Stress Transference

- To repair welds suffering from cyclic axial loading, composites can be used.
- Adhesive shear properties are very important.
  - If adhesive is too brittle, may crack and fail.
  - If adhesive is too rubbery, load may not transfer.
Shear Strength

- Max adhesive strength occurs at cure temperature
- Any change in temperature creates a thermal stress due to differences in CTE
  - If applied at ambient and brought up to temperature, could cause early adhesive failure

Approximate Cure Temperature

![Graph showing shear strength vs test temperature](image-url)

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Conclusion

• There are many thermal considerations in any low or high temperature system
  • Changes in mechanical strength
  • Maximum temperature limits
  • Restrictions on application
  • Thermal expansion / contraction

• If everything is considered and accounted for, composites can provide an excellent repair for a large temperature range
Any Questions?

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