Material Failures in Fire Protection Systems

March 4, 2014
University of Central Florida (UCF), Orlando, FL

Jeff Pfaendtner – Materials/Metallurgical Engineer
Crane Engineering Inc., Plymouth, MN
Forensic Engineering

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• Structural Engineering
• Fire Protection Engineering
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Introduction

Failure Modes Relate to:
- Design
- Manufacture
- Installation
- Service Environment
  - Water chemistry
  - Nominal Operating Temp & Temp extremes
  - Service & Maintenance
  - Age
  - Geographic location
  - etc.

A flaw becomes a defect when it prevents the part/system from functioning as designed.
Case Studies

1. CPVC “Spider Lines” (M)
2. CPVC Environmental Stress Cracking (I&E)
3. CPVC Environmental Stress Cracking (I&E)
4. CPVC Other Incompatible Materials (I&E)
5. Sprinkler head: Crack in Frangible Bulb (M)
6. Sprinkler head: Casting defect (M)
7. Sprinkler head: Galvanic/Crevise Corrosion (D&M)
8. Steel pipe: Microbiologically Induced Corrosion (I&E)
9. Steel pipe: Pitting Corrosion (I&E)
10. Brass Fittings: Stress Corrosion Cracking (D, M, E)
11. Steel pipe: Light wall Pipe (D)
12. Freeze failures (I & E)
13. “Rube Goldberg” type failures (E)

Key:
D – Design
M – Manufacture
I – Installation
E – Environment
Case 1 - “Spider Lines” in PVC Pipes

- Straight fracture observed in CPVC pipe after less than one year of service.
Case 1 - “Spider Lines” in PVC Pipes

- Spider lines are “virtual cracks” in pipe
- From manufacture process
Case 2 – CPVC & Glycol

- Failure after 10 years in service.
- System was a “glycerin” filled system, but testing revealed the presence of glycol.

→ Environmental Stress Cracking (ESC) from residual glycol
Case 3 – CPVC & Alkane Oils

- Wet system in condo building
- Heated garage is Allied XL steel
- Steel to CPVC transition (living space)
- Water leaks in CPVC after ~3 years
Case 3 – CPVC & Alkane Oils

- External view of CPVC pipe
- Through-thickness cracks
Case 3 – CPVC & Alkane Oils

- Internal view of CPVC pipe
- Multiple cracks developing on ID surface
Case 3 – CPVC & Alkane Oils

- Internal view of CPVC pipe
- Cracks developing around cement drip
Case 3 – CPVC & Alkane Oils
Case 3 – CPVC & Alkane Oils

→ Environmental Stress Cracking (ESC) from residual thread cutting oil
Environmental Stress Cracking (ESC) is a time dependent (slow) cracking mechanism.

ESC has three main requirements:
- Susceptible material (e.g., CPVC pipe)
- Stress (either residual in the material, or applied stress)
- Incompatible chemical species (certain oils, plasticizers, glycols, etc.)

Failures are usually manifested as slow leaks, but sometimes as catastrophic breaks.
Case 4 – Incompatible Materials

- CPVC potable hot water line to irrigate trash chute in high rise condo.
- Pipe failure occurred after several years in service at location of contact with grommet.
Case 4 – Incompatible Materials

- Plasticizer diffuse from one plastic into another
- Pipe weakens & ruptures
Case 5 – Crack in Frangible Bulb

- Sprinkler head deployed unexpectedly causing water damage.
- Purple staining observed on frame arms & body.
Case 5 – Crack in Frangible Bulb

- Crack develops & propagates
- Fluid leaks from bulb over time
- Bulb breaks; water flows
Case 6 – Casting Defect in Sprinkler Head

- Unexpected deployment of attic sprinkler head
- Deformed load screw

200°F Attic head
Case 6 – Casting Defect in Sprinkler Head

- SEM & X-ray imaging shows evidence of cracks in one frame arm
Case 6 – Casting Defect in Sprinkler Head

- Difference in compliance between frame arms creates mechanical imbalance
- Frangible bulb “walks” off set screw w/ thermal cycling
Case 7 – Galvanic/Crevise Corrosion

- Sprinkler head leaked after 3 years in service.
- Water damage to condo.
Case 7 – Galvanic/Crevice Corrosion

- Pinhole leak in Belleville spring (under seal)
- Corrosion over months/years
Case 7 – Galvanic/Crevice Corrosion

- Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS)
Case 8 – Microbiologically Induced Corrosion (MIC)

- “Dry” system developed pinhole leaks 5 years after installation.
- Tubercles observed on pipe ID.
- Water supply not “corrosive”.

- High levels of aerobic bacteria, low nutrient bacteria, and acid producing bacteria found.
Case 9 – Pitting Corrosion

- A wet system developed pinhole leaks after 25 years.
- Water testing showed high levels of dissolved oxygen, high hardness, and high levels of dissolved solids.
- Bacterial cultures showed low or undetectable levels of bacteria
Case 10 – Stress Corrosion Cracking (SCC)

- Catastrophic failure of brass hose valve
- $1M+ water damage to large commercial building
Case 10 – Stress Corrosion Cracking (SCC)

- Catastrophic failure of brass hose valve
- Multiple cracks

C37700 Forging Brass
- Copper: 58.0 – 62.0 wt.%
- Lead: 1.5 – 2.5 wt.%
- Iron: 0.3wt% max
- Other impurities: 0.5% max
- Zinc: Balance

Raw material costs:
- Copper: $3.32/lb.
- Zinc: $0.85/lb.
Case 10 – Stress Corrosion Cracking (SCC)

- Brass alloy defective
- Zinc too high; Iron impurity too high
Case 11 – Light wall Pipe

- Leaking NPT joints in factory producing printed circuit boards
Case 11 – Light wall Pipe

0.5mm = 0.02 inch
Case 11 – Light wall Pipe

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- **R² = 0.8983** for Schedule 40
- **R² = 0.6746** for 2in. BLT

Schedule 40

2in. BLT

Linear (Schedule 40)

Linear (2in. BLT)
Case 12 – Freeze Damage

- Component failure due to volumetric expansion of freezing water (~9 vol%)
Case 12 – Freeze Damage

• Freeze failures often yield multiple cracks
Case 12 – Freeze Damage

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Case 12 – Freeze Damage

- Freeze-up can induce large scale deformation
Case 12 – Freeze Damage

- Freeze-up can induce large scale deformation
Case 13 – Special Environmental Effects
Summary & Final Thoughts

• All materials have their own vulnerabilities, and therefore their own application issues.
• No component is immune to failure.
• A variety of failure modes are operable in fire protection systems.
• Failures can occur in all stages of life of the system.
• Failure prevention involves good system design, material choice, good installation & maintenance
  ➢ taking local environments into account