

REMFI Case 1

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Thermal Cycling–Induced Fatigue in Brazed Aluminum Heat Exchangers (BAHX)

Incident

A blast tore into the Enterprise Pascagoula facility in Moss Point, Mississippi - flames surging as support systems gave way, back in June of 2016. Months passed before a full account emerged; by early 2019, investigators had finalized their findings. The culprit? Thermal stress building inside aluminum core heat exchangers over time. Instead of steady performance, temperature shifts wore down metal joints until tiny fractures appeared. Once those breaches formed, gas seeped out - eventually sparking fire when conditions turned right. Follow-up reviews confirmed the pattern: cycling temperatures weakened components, leaks developed, combustion occurred, and production halted far longer than expected. [1,2]

What breaks things most? Thermal fatigue. Temperature shifts make materials want to stretch or shrink - yet they're held tight, unable to move freely. This mismatch piles up stress again and again. Inside BAHX units, heat doesn't spread evenly. Fins, plates, connections - they each warm or cool at different speeds. Sudden changes make it worse. Stress concentrates right where pieces join. Tiny deformations add up. Slowly, damage takes hold.

When stress shifts direction repeatedly, weak spots start to form - these show up as cracks in surface layers or gaps between inner sections, typically around areas under heavy strain like joints or perimeter regions. [3]

Frequent shifts in temperature often come from startups, shutdowns, or uneven heat flow - each cycle adding stress without immediate signs. Some changes are sudden; others happen again and again. Over months or years, these fluctuations begin to matter more than expected. [2,3]

Some parts of the heat exchanger warm up faster than others, while cooling happens unevenly across sections. Since the assembly is rigid due to brazing, pieces that expand or shrink at differing speeds can't adjust freely - instead, they resist one another. This resistance builds repeating stress within the material over time. [3,4]

Where plates meet, at bends or fastening spots - especially near edges - the load intensifies. These zones bear heavier burden than nearby material. Stress builds unevenly there, so damage often starts early in those sections. Cracks tend to begin where such weak points exist. [3,4]

A single crack might stay small, yet repeating pressure nudges it wider over time. What makes cap-sheet splits significant isn't just their appearance - it's how they tend to push fluids out where you can see them. Internal layer separations behave differently; once cracks form there, liquid sneaks through areas meant to stay isolated, shifting from pressurized to relaxed sections without warning. These hidden channels rarely show up when inspections follow standard patterns.

A shift in temperature patterns set off stress chains inside the stiff brazed joint - each warm-up and cool-down tugged at the metal differently. Uneven stretching and shrinking locked in tiny strains with every round, piling up damage bit by bit. That slow grind lines up with what we see in durability studies: when heat flickers, materials wear down through repetition. Inside BAHX units, sharp thermal jumps nudge small flaws into existence, each cycle adding another notch toward breakdown. Evidence backing this view shows up in several technical sources. [3,4,5]

What played a role? Not the root reason, but things that made harm spread faster or consequences heavier. Each added pressure gave more weight to how bad it got. Some nudged timing forward. Others deepened impact where it hit hardest. None replaced the primary trigger - just shaped its path.

Cycling more often, dealing with broader shifts in temperature, or facing quicker changes in heat - all tend to stretch materials further, ramping up wear over time. [3,5]

Far beyond textbook estimates, actual operating patterns often stretch longer - particularly when systems wobble or flicker through quick repeats. This gap, rarely flagged, slowly feeds wear by piling on stress rounds. [2,3]

Failures might not give early warnings when cracks grow fast - leaks aren't always reliable signals. Hidden damage, like fluid seeping between internal layers, can escape detection entirely. Signs may appear only moments before collapse, if at all. This limits how well leak-based monitoring works in certain cases. [2,3]

1. Detection and Monitoring Lessons Quantify the real drivers of damage

Fault lines in materials often trace back to more than just high temperatures. Shifts between hot and cold areas matter - so do the speed at which things heat up or lose warmth when changes hit. These shifts play a clear role in how parts wear down over time under thermal stress. [1,3]

2. Monitoring must reflect what's happening at the exchanger

3. Prefer leading indicators when possible

Back when, a leak often meant the end was near for BAHX models. Lately, systems have been leaning on embedded sensors or predictive flags - ways to swap sudden breakdowns with scheduled upkeep, assuming setup matches actual use. [3]

Safety fixes often start small - better routines set the stage before tools or tracking come into play. Only once habits are steady does hardware get redesigned. Changes take root most reliably when behavior shifts precede machinery tweaks.

A. Operational measures (ease repeated stress)

- Lower the range of temperature shifts when feasible through careful operations.

Stability in operation tends to cut down on redundant cycles. [2,3,5]

B. Monitoring and data practices (boost observability)

Alerts fire when movement rhythms or heat shifts stand out - patterns matter more than set points.

- Store high-resolution historical data so it's usable for root-cause work and trend tracking. [1,3]

C. Mechanical layout and upkeep (build tougher systems)

- Focus inspections near mounts, joints, attachment points, and known high-strain zones where expansion and rigidity collide.

Fatigue-related leaks showing up again might hint at deeper issues - patterns of repair could point toward redesign needs, swapping components out, or narrowing how systems are run. [3]

When temperatures shift repeatedly, materials wear down. To manage this, some teams set boundaries based on how systems respond to heat changes. Risk assessments help spot weak points before failure happens. Instead of waiting, scheduled checkups catch early signs of strain. These steps form a routine that follows the rhythm of thermal stress. Decisions come from observed patterns, not guesswork. [1,5]

1. Transferable Design Rules High performance can mean sharper transients, so heat management is reliability management

Facing high temperatures isn't just a matter of performance - how well devices endure stress shapes their survival. [3,5]

2. Thermal fatigue is a system behavior, not a single-part problem

Stopping things from happening again involves keeping an eye on how frequently they repeat, their intensity, and the speed of buildup - alongside improving detection of what truly leads to damage. [1,3,5]

Conclusion

Thermal cycling can slowly damage a tightly constrained BAHX until cracks form and leaks occur, sometimes in ways that are hard to detect. Preventing repeat failures depends on limiting damaging temperature swings, improving monitoring near the exchanger, and taking stronger mechanical action when fatigue keeps showing up. [1,3,5]

References

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