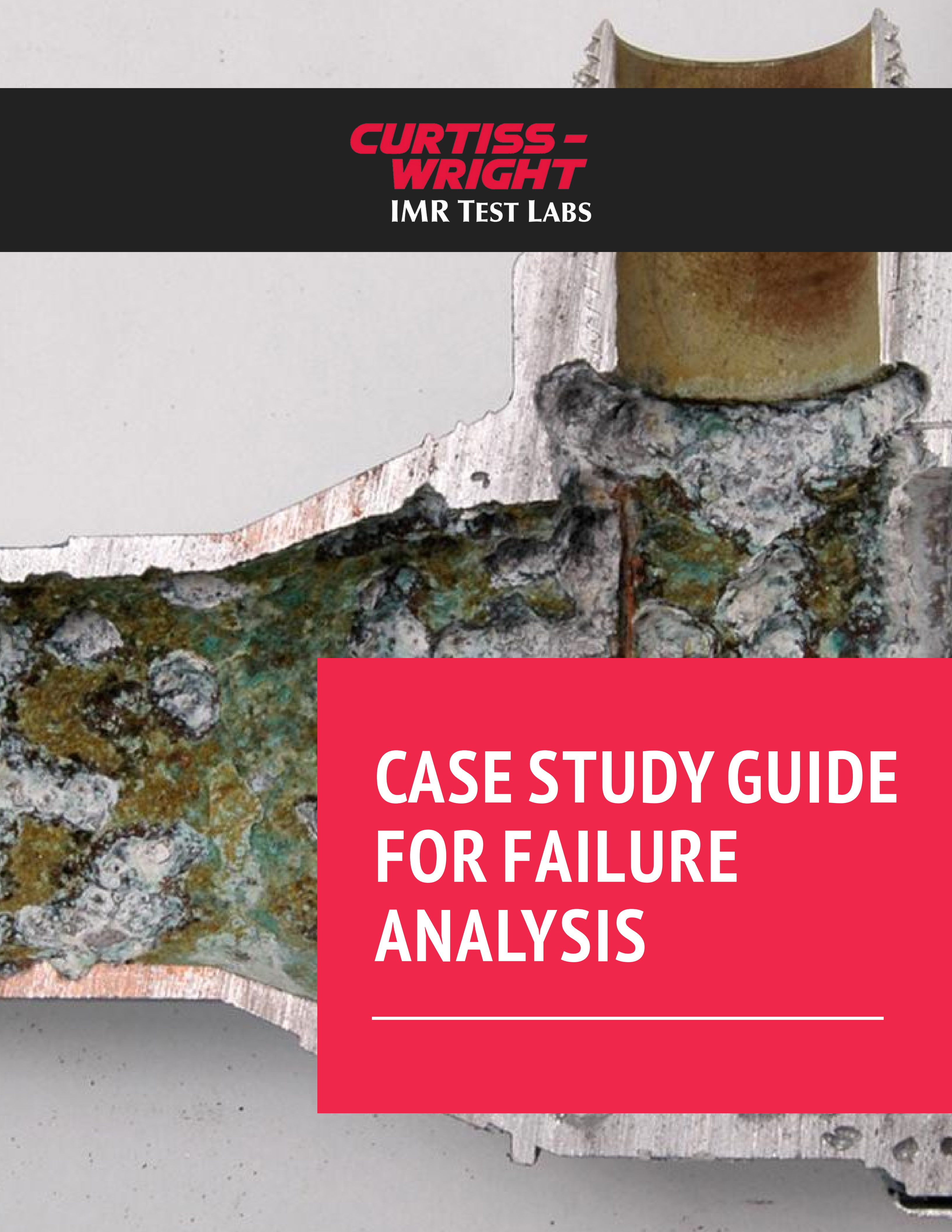


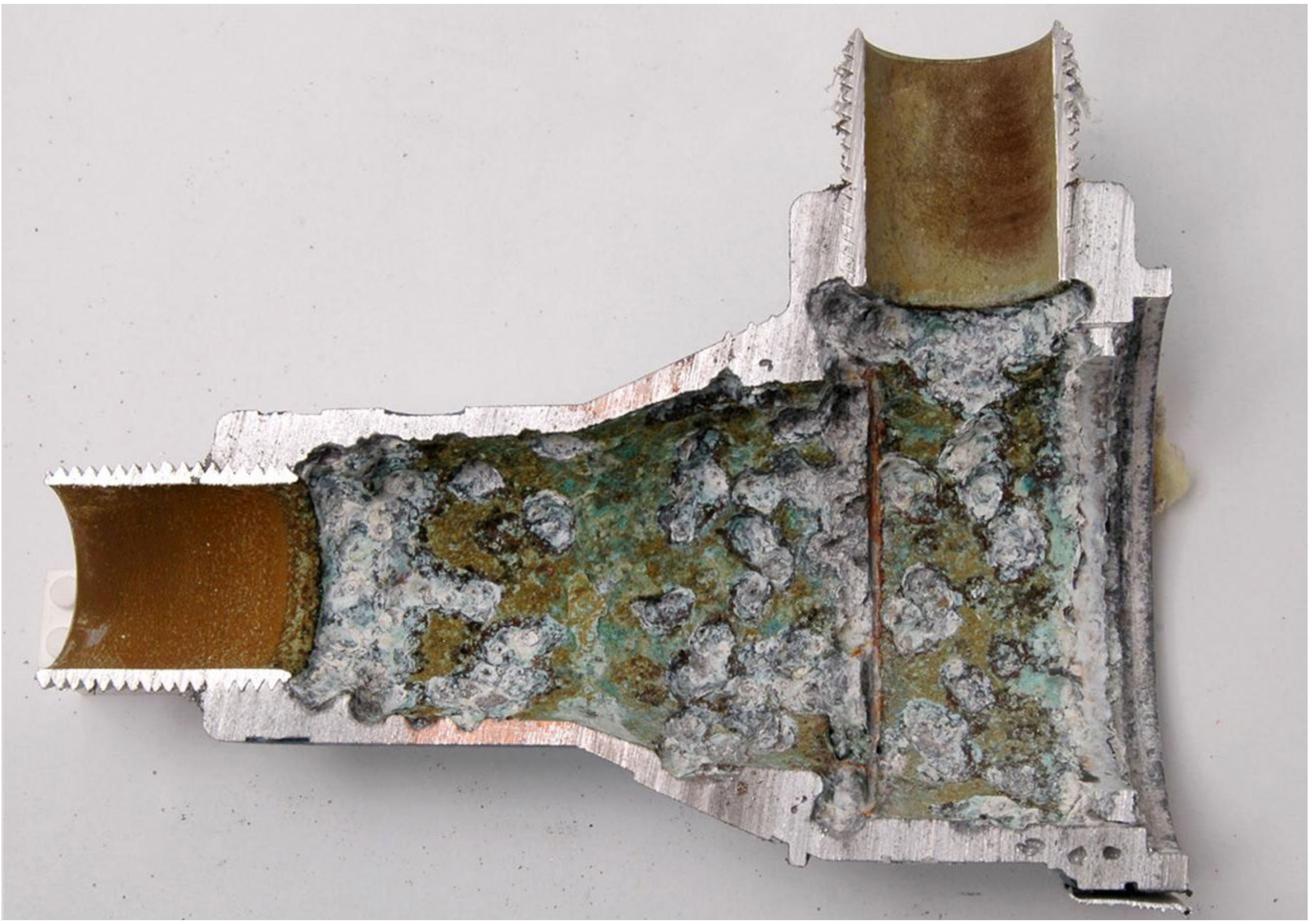
CURTISS-WRIGHT

IMR TEST LABS

CASE STUDY GUIDE FOR FAILURE ANALYSIS

Analyzing Failures is a Critical Process in Manufacturing and Product Development

One of the main goals in determining the cause of problems is preventing future recurrences. The problems are not always obvious, so having an open mind during the analytical process helps testing professionals utilize a multi-disciplinary approach. Avoiding pre-judgement on the root cause of the failure allows the analytical data to speak for itself. Of course, this is where an experienced lab technician, engineer or chemist can elevate the analyses and deliver actionable knowledge to help the customer implement a corrective action strategy.

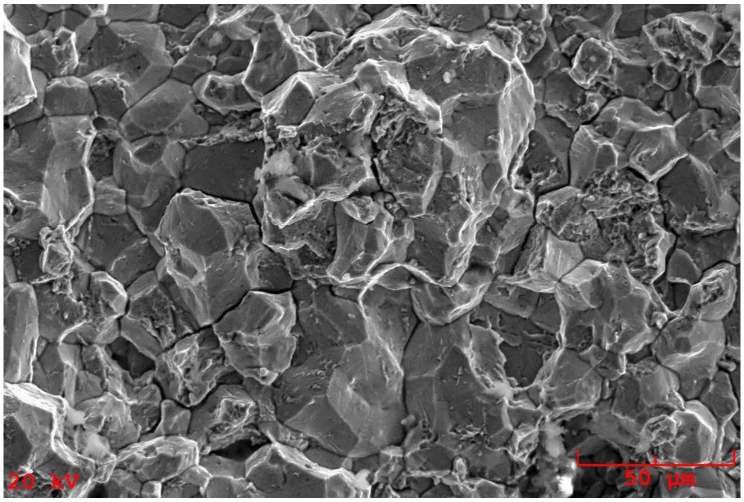


Failure analysis of a valve due to MIC (microbial influenced corrosion)

Case Studies:

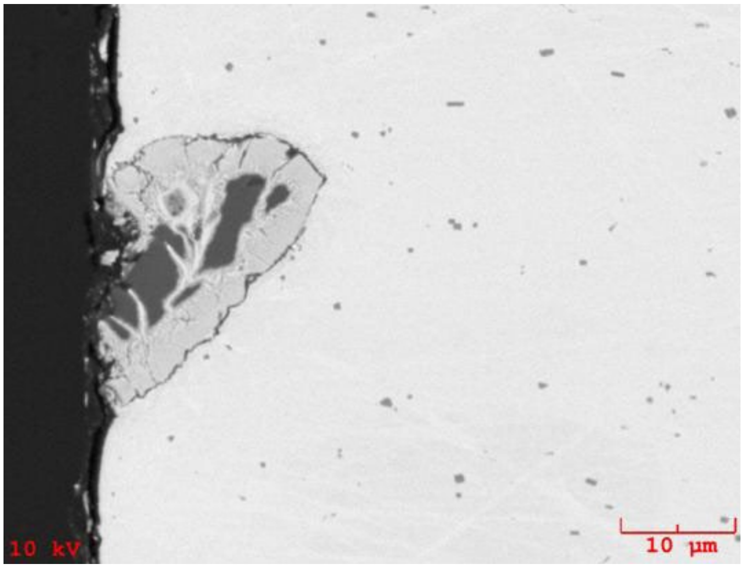
Hydrogen Embrittlement Failure Analysis

One of our clients reached out for help with a failure analysis of a fractured component that failed during routine testing. IMR was asked to confirm a preliminary root cause analysis from another test lab the end-user had sent the part to. Additionally, IMR was supplied with swabs from foreign deposits and some additional pieces to analyze.



Failure analysis - hydrogen embrittlement

These swabs, as well as additional particulate samples taken from inside the parts, were analyzed via SEM-EDS to determine composition. The analysis showed embedded particles, primarily composed of alumina, silicon oxide, and carbides. Chlorine was also detected.



As-polished embedded particle on inner surface in area exhibiting pitting

Pitting was observed on the surfaces near where the particles were collected and the fracture occurred. The part is exposed to high-temperature steam in-service in a stagnant area without a lot of flow. Condensation preferentially collects on particles, which can contribute to pitting corrosion. There is also hydrogen in the process steam, which in addition to the pitting, allowed IMR to conclude hydrogen embrittlement as a root cause for failure.

Recommendations to prevent future failure included evaluating the cleaning process as well as inspections of the population of parts for signs of pitting. The client also suggested switching to a component with a thicker wall to lower the local stresses to ensure structural integrity even if embrittlement were to occur in the future.

Failure Analysis of a Bellow Due to Undersized Welds

IMR received a pair of bellows assemblies with cracks in the welds for failure analysis.

After mounting, polishing and metallographic analysis of four sections from each assembly, it was determined that all 8 locations failed to meet the customer-supplied fillet angle requirements and six of eight failed to meet weld size requirements. Samples that were taken from areas where there were no visual crack indications also contained cracks originating at the weld root.

Mounted and etched sample showing cracking originating at the weld root. Similar cracks progressed to the outside surface and were detected by the customer.

One crack from each assembly was opened to examine the fracture surface using an optical stereoscope and a scanning electron microscope (SEM). The overall morphology of the crack surfaces is consistent with multiple origin fatigue originating at the root of the weld.

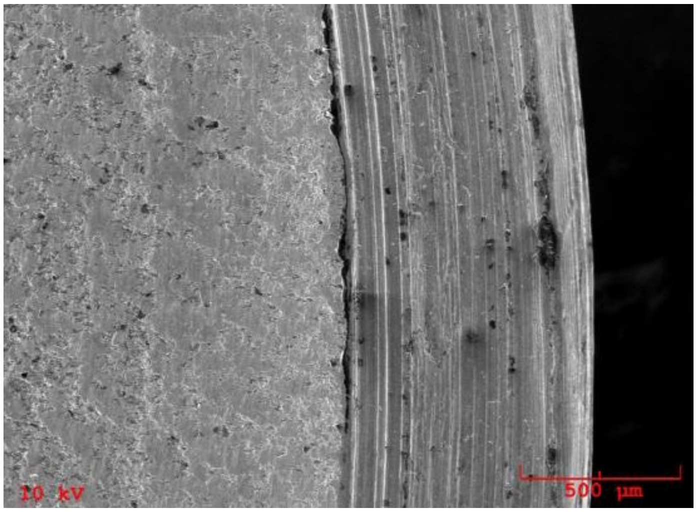
It was determined that undersized welds are the likely cause of the cracking and that there was no evidence of corrosion, weld defects or loose bolted connections.

Fatique Failure of a Pin

A 4150 steel pin was received for failure analysis; the fracture was determined to be due to rotating bending fatigue.

The sample was consistent with the supplied chemistry specification with the exception of a high sulfur value. This implies that the material was resulfurized for machinability.

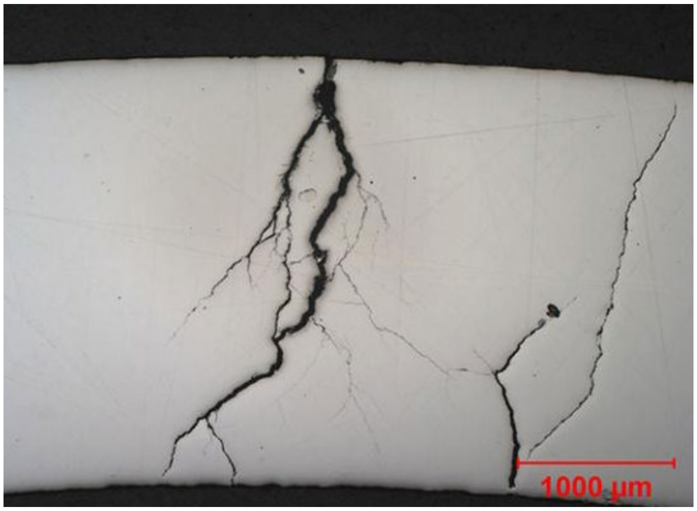
The fracture occurred at a machined radius near the center of the pin. The machined radius exhibited rough machining lines which may have acted as crack initiation sites. A finer finish on the part would likely result in improved fatigue performance.



SEM view of the fracture surface with deep machining mark at the edge.

Failure of Pipes Due to Stress Corrosion Cracking

Two sections of 304 stainless steel pipe were received for analysis of the source of leaks. Additional materials were also received, including insulation, strapping, two process fluids and a water sample from the DI system used to mix the fluids.



Failure analysis of cracks in the pipe section – as polished

One pipe showed minor pitting and the other contained a network of fine cracks. The cracks appear to have originated on the outside of the pipe. Both pipes were covered with debris.

Drops of the process fluids and the DI water were dried on aluminum stubs.

The DI water contained numerous sodium chloride deposits. Ion chromatography (IC) testing confirmed that the DI water sample contained 9 ppm of chlorides. This is the likely source of chlorides that caused the corrosion.

The other dried process fluids, debris, pieces of the supplied insulation and strap material were analyzed using scanning electron microscope with energy dispersive spectroscopy (SEM/EDS) equipped with a light element detector. None of these materials contained any chlorine.

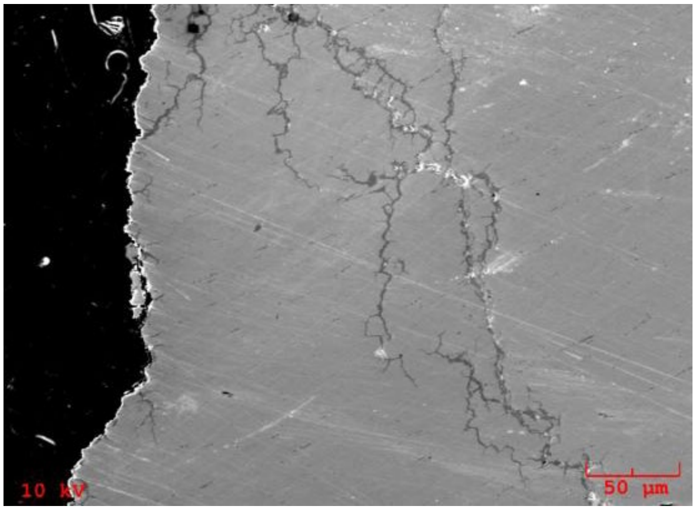
The debris on the surfaces of the tubes was from the silica-based insulation and contained sodium and chlorine, likely from trapping moisture against the pipes. 300 series stainless steels are susceptible to stress corrosion cracking (SCC) in moist chloride environments

Failure Analysis of Steam Turbine Wheel Due to Hot Caustic Stress Corrosion Cracking

A steam turbine wheel with fractures at the locking bucket location was received for fracture and microstructure examination, chemistry, and mechanical property testing.

The wheel chemistry and mechanical properties meet the requirements of the customer supplied specification. Examination of the fracture surfaces on the wheel indicated a primarily intergranular fracture surface that was somewhat compromised by corrosion. An intergranular fracture surface of the wheel material is indicative of either an embrittlement mechanism and/or corrosion. Metallographic examination confirmed that the wheel experienced intergranular stress corrosion cracking (SCC).

The chemistry and hardness of the locking pin are consistent with the tool steel as specified on the drawing. The locking pin fracture surfaces exhibited some coarse transgranular texture in undamaged areas. Only a very small area of ductile dimples were observed. The fracture surfaces appeared quite complex indicating a possible corrosion mechanism was present. Fractography and microstructure examination confirmed that the pin experienced transgranular SCC.



Secondary electron image of pin cross section near the fracture surface. Note complex crack pattern indicative of caustic stress corrosion cracking.

Nonmetallic Failure Analysis

With a nonmetallics lab in-house, we are well-positioned to handle your root cause analyses on mixed materials and finished products. Our polymer, ceramics, coatings and fiber-reinforced composites experts are well-versed in the failure modes of these materials. They can provide you a clear, concise root cause analysis report that explains the contributing factors and suggestions to prevent recurrence.

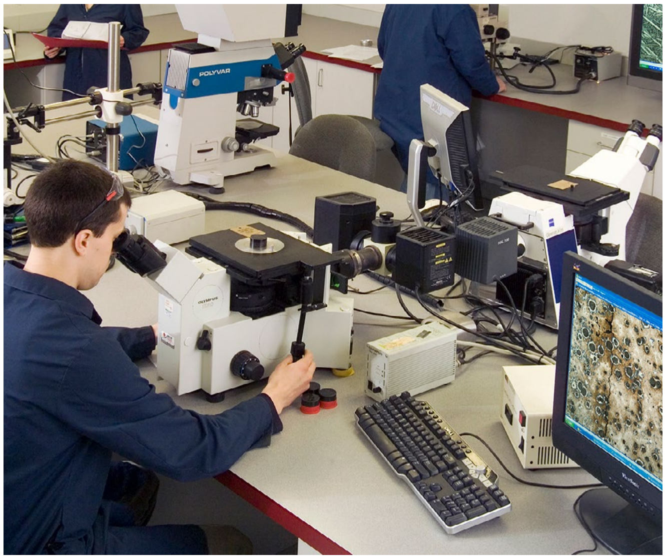
Failure Analysis Services:

- Fracture Evaluation
- Failure Mode Determination
  - Fatigue
  - Fractography
  - Overload
  - Ductile/Brittle Failures
  - Chemical Attack
  - Stress Corrosion Cracking
- Corrosion Simulation and Failure
- Contamination and Corrosion Analysis
- Particle Analysis/Identification
- Filter Residue Analysis
- Process/Manufacturing Problem Analysis
- Material Selection/Processing/Design Recommendations
- Engineering/Process Problem Solving and Consulting
- Hosted Inspections
- Weld Analysis
- Litigation Related Failure Analysis
- Expert Services Consulting
- Third Party Inspections/ Examinations

Failure Analysis

Working with IMR Test Labs

IMR Test Labs should be your first choice for your next failure analysis. We are an experienced and knowledgeable team trained to tackle your failure analysis needs from simple fractures to complex litigation cases.



We have extensive failure analysis capabilities including metals, polymers and composites, welds, coatings, finished products and more. Our Metallurgical Engineering staff provides insight into contributing factors of the failure so you can prevent recurrence.

With a full chemistry lab (including non-metallics) and a well equipped mechanical fatigue lab, our engineering staff has numerous resources to help you and your team.

ABOUT US

We're an international firm offering a complete scope of materials testing services, including chemical analysis, cleanliness testing, corrosion testing, mechanical testing, metallurgical analysis, failure analysis, fatigue testing and much more.

We have five facilities, located in Ithaca, New York; Louisville, Kentucky; Portland, Oregon; Singapore; and Suzhou, China. IMR demonstrates an on-going commitment to serve our clients' analytical needs, wherever they may be.

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