

Analysis of Failure Including Environmental Effects, Elements of Forensic Science in Failures

To appreciate why failures occur, there are certain factors that should be recognized:

1. All engineering materials are reactive chemicals; the surprise is not that they fail, the surprise is that they work.
2. Environments are more powerful in their effects than stress since the chemical energy change in corrosion is substantially greater than that due to stress. Materials can be readily perforated with no applied stress at room temperature and in nominally innocuous environments. Rarely do even mechanically related failures, including fatigue, occur without environmental acceleration.
3. The range of environments over which materials are reliable is relatively narrow; good corrosion resistance in one domain is not a good indicator for another.
4. Following well established specifications, codes and standards does not prevent failures.
5. Corrosion allowances do not prevent failure.
6. Nominally high performance alloys such as stainless steel, high strength steel, and titanium are among the most failure prone of materials. While such materials can perform well, they often fail catastrophically.
7. Failures rarely occur because of bad heats (batches) of material.
8. Design is usually conducted in terms of meeting warranty periods; failures due to corrosion usually occur after the warranty period. See example in Figure 1.

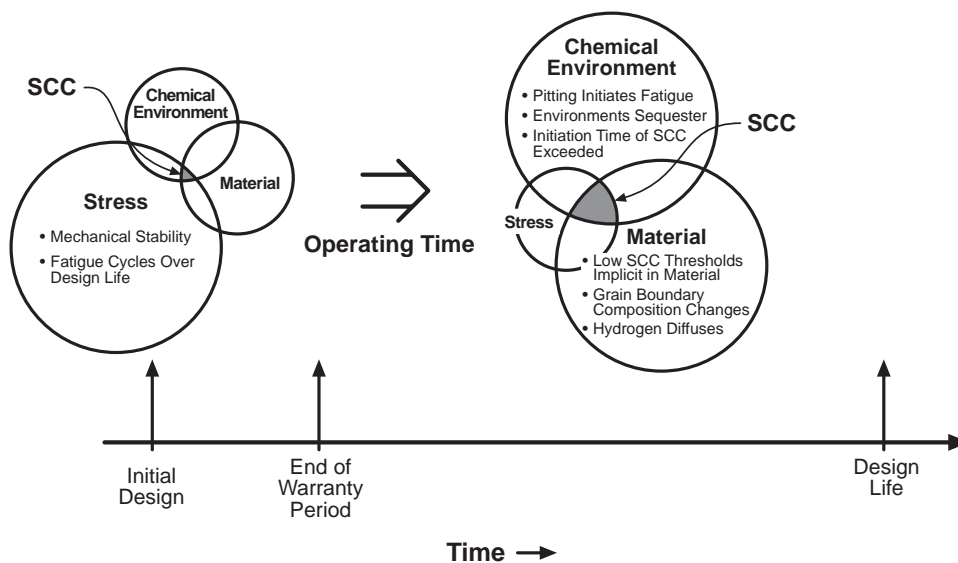


Figure 1 Schematic view of the relative importance of chemical environment, stress and material to determining the life of components over time.

9. HAZOP (Hazardous Operations Analysis) and FMEA (Failure Modes and Effects Analysis) do not prevent failures unless they include the necessary inputs as shown in the CBDA.

10. Causes and modes of failure:
 - “Cause” is what is fixed and is usually institutional: e.g. design bases, lack of failure definition, inadequate inspection, inadequate monitoring, lack of systematic approach as in LAM, penny-wise and pound foolish design choices, non-critical dependence on prior field experience, designing with only warranty objectives, and basing “forty-year life” only on fatigue analysis.
 - “Mode” is the process by which failure occurs: chloride enters a system and the stainless steel fails. In this case, the chloride is not the cause but part of the mode.
11. “Root cause” analysis is misleading since emphasis in such work is on the mode and not the cause; thus, little is resolved.
12. The indications of possible failures are often already present before the failures occur.

Staehle approach to failure analysis based on Corrosion Based Design Approach (CBDA) and Location for Analysis (LAM):

1. Make no assumptions about the mode or cause.
2. Measure and photograph all aspects of the failure, as available, and the context in which the failure occurred.
3. Determine all aspects of the pre-existing environments and conditions including: chemical, stress, thermal, flow factors.
4. Review all aspects of published literature that relate to the failure, including international publications.
5. Examine failed parts in detail: relationships, surface chemistries, failure mode, deformations.
6. Analysis of failure is the opposite of justice: Guilty until proven innocent.

Staehle experience with failure analysis:

1. As a professor in metallurgical engineering at Ohio State taught course for ten years in failure analysis as a means for guiding the selection of materials. Student problems included specific industrial problems and required weekly written analysis of failures as well as critique by English department. Format for written analyses included:
 - a. Most likely causes
 - b. Mode and description of mode
 - c. Short range fix
 - d. Long range fix
 - e. Information necessary to define cause and mode.
2. Taught course in failure analysis at General Electric in early 1970s.
3. Has consulted in most significant industries.
4. Served as an expert witness in litigations since 1972.
5. Has developed CBDA and LAM methods to prevent failures and assure performance.