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Standard Guide for Corrosion-Related Failure Analysis[1]

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1. Scope

1.1 This guide covers key issues to be considered when examining metallic failures when corrosion is suspected as either a major or minor causative factor.

1.2 Corrosion-related failures could include one or more of the following: change in surface appearance (for example, tarnish, rust, color change), pin hole leak, catastrophic structural failure (for example, collapse, explosive rupture, implosive rupture, cracking), weld failure, loss of electrical continuity, and loss of functionality (for example, seizure, galling, spalling, swelling).

1.3 Issues covered include overall failure site conditions, operating conditions at the time of failure, history of equipment and its operation, corrosion product sampling, environmental sampling, metallurgical and electrochemical factors, morphology (mode) or failure, and by considering the preceding, deducing the cause(s) of corrosion failure.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E3 Guide for Preparation of Metallographic Specimens
E1459 Guide for Physical Evidence Labeling and Related Documentation
E1492 Practice for Receiving, Documenting, Storing, and Retrieving Evidence in a Forensic Science Laboratory
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G46 Guide for Examination and Evaluation of Pitting Corrosion

3. Significance and Use

3.1 This guide is intended to assist those encountering corrosion or possible corrosion as a causative factor in a failure analysis.

3.2 This guide is not an absolute plan that will identify the cause of corrosion in all failure analyses.

3.3 This guide is intended to help an investigator identify significant sources and types of corrosion information that may be available for failure analysis.

3.4 Appendix X1 contains a checklist that is intended to assist in corrosion-related failure evaluations.

4. Organizing the Analysis

4.1 Early recognition of corrosion as a factor in a failure analysis is critical to any such investigation. Therefore, it is generally desirable to conduct the analysis as soon as possible after the apparent failure. It is *always* desirable to protect the physical evidence until the analysis can begin. Much important corrosion information can be lost if a failure scene is altered or changed before appropriate observations can be made.

4.2 A written plan for the detailed analysis should be prepared. The plan may include methods of documentation (photographs before and during analysis, sketches, statements), responsibilities of parties, reporting needs, and scheduling.

4.3 If the capability (corrosion knowledge and experience) of in-house personnel and availability of resources are inadequate to make the analysis in a timely manner, it may be expedient to seek third party services.

5. Failure Site Conditions

5.1 When possible, an overall examination of the conditions at a failure site prior to cleaning, moving, or sampling debris should be conducted. Impressions as to physical arrangements, odors, colors, textures, and conditions of adjacent structures can provide important clues as to active corrosion processes.

5.2 Photographs or videotapes serve as documentation of the observations. Color photographs are preferable. It is helpful to include labels and indications of size, location, and orientation in the photographs. Photographs before, during, and after sampling are recommended.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

5.3 Sketches and drawings with notes as to detailed observations can be beneficial for later evaluations. Locations of samples and photographs may be shown.

5.4 Interviews with those who were present or nearby when the failure occurred would be appropriate. Information on time, sights, sounds, and conditions can be gained during such interviews.

6. Operating Conditions At Time of Failure

6.1 Ascertain the operating conditions from operator's logs, recorders, and data loggers (verify the accuracy of time records). Special attention should be given to the stability of the operating conditions, for example, were they stable or variable. Conditions of corrosion concern could be temperature, pressure, flow rate, velocity, process stream pH and chemical composition, time, and weather.

6.2 Special attention should be given to out-of-specification or other abnormal or unusual upset conditions.

6.3 It may be necessary to plot or track operating conditions for an indefinite period of time prior to the detection of failure to more clearly identify any unusual, contributory operating conditions.

6.4 If similar, parallel equipment at the same or other location was operating at the time of the corrosion-related failure, note the operating conditions as a reference point. Such information could be useful in judging the normalcy of the operating conditions associated with the failure.

6.5 Corrosion monitoring instruments and coupons, if present, should be examined to help document operating conditions at the time of failure.

7. Historical Information

7.1 Historical information, when available, is extremely useful in understanding some situations. All of the types of information noted may not be useful. Often in cases of older equipment, historical information may be nearly impossible to find because of lost files or retired personnel. Based on cost, time, and anticipated benefit, a judgement must be made as to the effort one should expend in retrieving historical information.

7.2 Useful details regarding original constructions may include, but are not limited to, design drawings and specifications, material specifications (composition, thermal treatments, surface treatments), joining (bolts, rivets, welds, adhesives), and surface treatments (coatings, pickling, etching, anodizing, plating, peening, grinding, insulation, or refractories).

7.3 Details regarding modifications made subsequent to original fabrication and prior to the corrosion-related failure may be extremely important because they often reveal less-than-optimum field work. Modifications may have been made for one or more reasons, including, but not limited to, problems with original design, changed service requirements, corrected earlier failures, and correction of safety and environmental concerns. The same types of details suggested in 7.2 should be considered regarding modifications.

7.4 Details regarding operating history may be important. Three types of operating information that may require documentation are original design parameters, chronology of nominal operating parameters, and anomalous operating parameters, including out-of-specification periods and significant downtime periods.

7.5 Maintenance, cleaning, and repair histories may be important and should be documented.

7.6 Changes in specification for, and sources of, process raw materials and supplies may be significant and should be evaluated.

8. Sampling

8.1 Careful sampling is critical to the successful investigation of corrosion-related failures. Sampling in corrosion investigations is similar to that used in forensic investigations by criminologists. Guide E1459 and Practice E1492 address issues of labeling and documenting field evidence. These standards may provide useful guidance during sampling for corrosion investigations.

8.2 The written plan suggested in 4.2 should be supplemented with a written sampling plan. The plan should specify a sample location, identification system, and method of collection.

8.3 Avoid contamination during sampling by using clean tools. Personnel should wear gloves to avoid fingerprints and personal contact.

8.4 Sample containers should be clean and sealable to protect samples from contamination and damage. The material of sample containers should be selected carefully to avoid undesirable interaction with samples. Each container should be dated and identified according to the sampling plan.

8.5 Samples of corroded and uncorroded materials may be useful in the identification of causative factors. Samples should be as large as practical to give analysts sufficient material to work with and to protect critical corroded areas from damage during cutting and transporting. If failure initiation location is apparent, it should be sampled. When cutting samples, consideration should be given to temperature control and to the introduction of cutting and cooling fluids that could alter the surface and metallurgical conditions. Because of the solubility in water of many corrosion products, samples must be protected from extraneous moisture.

8.6 Corrosion products and deposits should be given special sampling treatment because they are often key elements in understanding the failure. Care should be used in the selection of tools for collecting these samples. Nonmetallic tools are often preferred because they present less chance for contamination of the sample or for damaging critical corroded surfaces. When there is insufficient corrosion product or deposit for easy field sampling, care should be used when handling material so that subsequent laboratory sampling may be conducted. Because of the solubility in water of many corrosion products, samples must be protected from extraneous moisture.

8.7 Process stream samples may be desirable. The most useful process stream samples are those taken from the failure location as soon after the event as possible. Delayed or typical process stream samples are less useful because there is no assurance that they represent the conditions at failure.

8.8 Special sampling procedures may be required when microbiological factors are suspected of being involved. Before taking such samples, consult *ASTM STP 1232* for guidance (**1**).[3]

8.9 Care should be taken during sampling to protect any fracture surfaces from becoming damaged. If partial reassembly is necessary, maintain an air gap between mating fracture surfaces. Bringing fracture surfaces together could eliminate very valuable information.

9. Evaluation of Samples

9.1 Compositions of samples of materials (including fasteners and weld beads), process streams, deposits, and corrosion products should be determined using appropriate analytical tools and techniques.

9.2 Metallic samples (including fasteners and weld beads) should be evaluated for metallurgical condition and structure. This evaluation may involve mechanical and physical property tests, metallographic examination of cross sections, and corrosion tests.

9.2.1 Selection of mechanical and physical property tests should consider the influence of service temperature and time on the properties being evaluated.

9.2.2 Selection of metallographic examination techniques should consider the influence of service temperature and time on the metallurgical structures being examined.

9.2.3 Corrosion testing of affected material may be necessary to identify metallurgical and environmental factors associated with the failure. Selection of corrosion tests should consider the suspected type of failure, the materials involved, and the suspected environment.

9.2.4 In some cases it may be necessary to remove corrosion products to permit evaluation. The guidance of Practice G1 can be used to remove corrosion products with minimal damage to the metal sample.

9.3 Metallic samples are often subdivided into specimens suitable for laboratory evaluation. The location and orientation of each specimen must be documented by one or more of the following: photographs, drawings, or written descriptions. Each specimen should be labelled to aid in identifying its original location within the sample.

9.4 Failure locations, such as pits, fracture surfaces, crevices, and generally attacked surfaces, should be examined, and measurements should be made to document surface chemistry, pit depths, crack dimensions, and metal losses and other modes of attack. These examinations often require the use of light microscopes, scanning electron microscopes (including energy dispersive x-ray spectrometers (EDS)), and other instruments. In some cases, cross sections from corroded areas may require examination (see Methods E3) to relate corrosion extent and morphology (for example, intergranular or transgranular) to metallurgical structure. In cases involving fracture, fractographic examination is recommended.

10. Assessment of Corrosion-Related Failure

10.1 Assessment involves the evaluation of observations from the failure location, operational information, materials evaluations, examinations of failure samples, and expert opinions.

10.2 Incorrect or out-of-specification materials, process streams, and operating conditions should be noted and described.

10.3 Unusual or unexpected species in corrosion products or deposits should be noted and described.

10.4 The type and extent of corrosion should be noted. The extent of corrosion may be determined by measurements and calculations of general corrosion rate, pitting penetration (see Guide G46), or crack growth rate. It may also be useful to compare these rates with expected rates from the literature or experience. Rate discrepancies should be investigated (for example, by laboratory simulations). This information will be useful in judging the suitability of particular materials.

10.5 From these observations and findings, the investigator should be able to identify the one or more causative factor(s) involved in the failure. In many cases, more than one factor will be suggested as having played a role in the failure. References to similar or related corrosion-related failures are often useful (**2-8**). The investigator may provide explanations and rationales for suggested corrective actions.

11. Report

11.1 General description of corrosion-related failure.

11.2 Operating conditions at time of failure.

11.3 Historical information.

11.4 Samples taken including photographs.

11.5 Evaluations conducted.

11.6 Results of evaluations.

11.7 Corrosion cause or causes of failure.

11.8 Suggested corrective actions, if any.

11.9 References.

11.10 Disposition of samples and records.

12. Keywords

12.1 corrosion; failure; failure analysis; sampling; type of corrosion

[3] The boldface numbers in parentheses refer to the list of references at the end of this guide.

APPENDIX

(Nonmandatory Information)

X1. CORROSION-RELATED FAILURE ANALYSIS CHECKLIST

X1.1 The following checklist is intended as a guide. It should remind the user of important considerations in dealing with corrosion-related failure analysis. All items listed may not apply to every situation. Similarly, additional items may be appropriate for some situations. The order of presentation has been found useful.

X1.2 *Identification of Key Factors*:

X1.2.1 Name of equipment.

X1.2.2 Name and description (including dimensions) of failed part.

X1.2.3 Date and time of failure.

X1.2.4 Location of failure.

X1.2.5 Accessibility of failure location.

X1.2.6 Names of key personnel.

X1.3 *Overview of Failure Conditions (Use Notes, Sketches, Photographs, and Video Tapes)* :

X1.3.1 Physical arrangement.

X1.3.2 Smells or odors.

X1.3.3 Colors.

X1.3.4 Deposits or residues.

X1.3.5 Surrounding conditions.

X1.3.6 Evidence of rearrangement or movement.

X1.4 *Overall Plan of Attack (Include Who, What, When, Where for Each Action)*:

X1.4.1 Types of information.

X1.4.2 Types of documentation.

X1.4.3 Sampling.

X1.4.4 Testing.

X1.4.5 Evaluations.

X1.4.6 Reporting.

X1.5 *Types of Information*:

X1.5.1 Conditions at Time of Failure:
X1.5.1.1 Process variables.
X1.5.1.2 Weather.
X1.5.1.3 Observations by personnel.
X1.5.1.4 Stability.
X1.5.1.5 Normal or unusual.
X1.5.1.6 Startup/shutdown/maintenance/layup/constuction.

X1.5.2 *History:*
X1.5.2.1 Design.
X1.5.2.2 Construction/fabrication.
X1.5.2.3 Materials of construction.
X1.5.2.4 Modifications.
X1.5.2.5 Operation.
X1.5.2.6 Process changes.
X1.5.2.7 Previous failures.
X1.5.2.8 Maintenance practices.
X1.5.2.9 Cleaning practices.
X1.5.2.10 Repairs.

X1.6 *Types of Documentation*:

X1.6.1 Operating charts and logs.

X1.6.2 Weather station observations.

X1.6.3 Process materials specifications (including materials safety data sheets (MSDS)).

X1.6.4 Materials of construction specifications and certifications.

X1.6.5 Fabrication specifications.

X1.6.6 As-built drawings.

X1.6.7 Sampling plan (including identification system photographs, and locations).

X1.6.8 Test reports.

X1.6.9 Site inspection notes, sketches, photographs, and video tapes.

X1.6.10 Interview notes and tapes.

X1.7 *Sampling* :

X1.7.1 Metal (failed and unfailed).

X1.7.2 Process materials.

X1.7.3 Corrosion products.

X1.7.4 Other deposits and residues.

X1.7.5 Environmental (air, water, soil, and other).

X1.8 *Testing* :

X1.8.1 Metal composition.

X1.8.2 Metal mechanical properties.

X1.8.3 Metal physical properties.

X1.8.4 Electrochemical test results.

X1.8.5 Corrosion product composition.

X1.8.6 Deposit and residue composition (including microbiological, if conducted).

X1.8.7 Environment composition (including concentrations and contaminants).

X1.8.8 Environment pH, temperature, and conductivity.

X1.8.9 Process material composition.

X1.8.10 Corrosion type and morphology (microstructures, fractography).

X1.8.11 Process simulation exposures.

X1.8.12 Surface analysis by EDS or other suitable technique.

X1.9 *Evaluations* :

X1.9.1 Test results versus specifications.

X1.9.2 Corrosion mechanism.

X1.9.3 Cause of corrosion.

X1.9.4 Measurements and calculations of extent of corrosion.

X1.9.5 Discrepancies (if any) between predicted and actual corrosion rates.

X1.10 *Reports* :

X1.10.1 Interim or progress.

X1.10.2 Final.

REFERENCES

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