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The importance of failure investigation is that the return on tools and parts can be increased substantially through understanding the failure/deterioration mechanisms and the interaction of operational conditions and material characteristics. Investigation of a failure should be a scientific, planned endeavor. Proceeding through various levels of data collection and evaluation, a hypothetical model of failure and sequence of events should be constructed.

Unfortunately, the fact that failure of a machine part or tool is seldom the result of a single factor makes failure analysis complicated. For example, a slight oversight in design, a localized deficiency in material, and overheating during grinding can combine to cause a catastrophic breakdown. In addition, analysts sometimes encounter situations where not enough information about system elements is available.

Failures are defined in terms of form and volume of load, nature and mode of failure, type of crack propagation, and material behavior. Each failure is unique with respect to its conditions and characteristics.

Because the function of tools is to form other materials, they experience higher levels of stress and accelerated conditions of deterioration. In this respect, each tool type is unique and must be optimized for that application. Tooling materials are commonly classified according to their major application, such as hot work and cold work tools. Others require high wear resistance, or must retain higher levels of dimensional stability.

Failure investigation is suitable for finding the root cause of process failures as well. For example, a poor quality steel sheet cannot be formed without tearing; a section of steel bar may be too hard to machine in a normal given time; or a mold surface may be too inferior to ever be polished. Such material-related technological problems could cause serious disruption of manufacturing schedules.

Each failure can be attributed to any of the following fundamental sources (or combination thereof):

- Deficiencies in design
- Imperfections in material
- Improper selection and processing of material
- Operational conditions
- Maintenance procedure
- Errors in assembly

This article describes eight steps required for a successful failure analysis. They amount to a general road map for successful failure analysis, although this article is focused on tools.

**Step 1: Describe the failure in its operational and environmental contexts**

Observe signs of any special pre-failure or post failure incident or unusual occurrences. What is the type of environment? Is it corrosive, humid atmospheres, high temperature, thermal shock, impact loading, cyclic loading, high contact stresses?

**Step 2: Collect the data/information**

The data and information phase includes an account of wreckage and debris, sequence of events, eyewitness description, historical data, identification, and recording of evidence. Look for service abuse, unqualified repair, replacement procedures, and misfit or excessive interference in assemblies.

Be sure to differentiate between pre-failure and post-failure events, and take material samples for laboratory analysis. A review of design requirements followed by verification with respect to material and processing quality sets the right path.

**Step 3: Fractography**

Visual observation augmented by nondestruct-
tive testing techniques is always a starting point. Determine failure/fracture initiation and propagation with respect to operational stresses and failure mechanisms such as corrosion, fatigue, or overload. Define the type of loading or stresses: bending, torsion, rotating-bending, tension or compression.

Describe the fracture by its features, fibrous, radial, and shear lip zone. The relative size of different zones is the result of interaction of destructive stresses and resistance offered by the metal. Shiny smooth fractures of tool steels may appear to be brittle, but they might have been preceded by some plastic deformation. This deformation is never as evident as in structural steels, and hence fracture appearance can be misleading.

**Step 4: Material evaluation and characterization**

Steels are alloys of carbon and other elements in iron. In any grade, some elements are intentionally added in controlled proportions, while others find their way into the metal through scrap and impurities carried into steel from primary refining processes. Many times these impurities go unnoticed, as they are rounded into traces in the manufacturer’s material certificates.

In failure analysis, chemical tests should verify the material chemistry according to the specified limits and tolerances. Specific tests and sampling procedures would be required to determine conditions of macro- or micro-segregation of alloying elements in steel.

Laboratory test data that are obtained under controlled conditions provide valuable information about the material capabilities. However, it is not always easy to extrapolate this information into all operational situations, which always have some ‘noise’ factors or unknowns. Static and dynamic technological tests or in situ testing provide better understanding of the material behavior in any given environment and loading conditions.

Microstructure is a portrait of thermo-mechanical processes, and is an essential element of all failure studies. An oxidized crack boundary, products of corrosion, unusual clustering of the indigenous/exogenous non-metallic inclusions, and the dispersion and distribution pattern of second phases, all influence material performance and serve as indicators of the quality of metallurgical processing. Complete understanding of metalworking processes is necessary to successfully understand their footprints on the microstructure.

**Step 5: Stress analysis**

In addition to external applied stresses, internal stresses may exist that do not become obvious until they overcome the structural coherency of the material and cause damage. Because tool steels possess higher yield strength, the level of internal stresses is also higher. Seizing of a cutting tool in the middle of a large steel block is one manifestation of internal stresses clamping on to the saw.

A two-dimensional or preferably three-dimensional finite element analysis will indicate the criticality of stress patterns along the body of the part/structure. Such analysis can be helpful in understanding the design and the effects of working conditions.

**Step 6: Synthesize the information/evidence**

- Does material comply with the specifications/expectations, or was it deficient?
- Does the material suit the application? What is the predominant material property required in the situation?
- How do extrapolations and tests fit in the failure model?
- Do fracture features and material evidence explain the applied stress model?

**Step 7: Conclude the findings**

- Material conforms to the specification
- Describe the failure mechanism
- Describe the root cause of failure

**Step 8: An integrated approach to solve the problem**

- Improve design, design for all processes
- Select and use materials rationally
- Improve processing, manufacturing techniques
- Add operational controls
- Improve preventive maintenance

Successful failure analysis provides the opportunity to improve the durability and operation of the tool, which means reduced down time and lower costs. It also leads to increased customer confidence in your ability to meet delivery commitments.

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