Post-Failure Evaluation of Mechanical Properties: A Primer

Thorough analysis of a failed component sometimes requires mechanical testing in order to determine whether the original mechanical properties of the component met the requirements specified by the designer or manufacturer. During this testing, care must be taken so that the true, original properties are determined, unaffected by the component’s service conditions or the circumstances of the failure event. Additionally, mechanical testing may be performed to determine whether the failure was induced by an abnormal or unexpected service condition.

The types of mechanical testing employed during a failure analysis are the same as tests performed on raw materials or new components. These tests are discussed within this article, as well as their variability and reliability, including observations and precautions to assist the failure analyst in properly determining original mechanical properties.

Introduction
A failure analysis often provokes a need for understanding that routine mechanical testing does not provide. The failure analyst is faced with unique situations and conditions with each individual investigation. As with all scientific experiments, there must be controls so that meaningful data will result. While it is impossible to apply a set of rules that cover all testing conditions, it is necessary to apply as many standard practices as possible. Failures are investigated as a means to discover and correct causative factors and thus prevent future failures. Failures are also sometimes investigated to determine the responsible party or parties. In the latter case, litigation leads to the close examination of the test results and close scrutiny of the methods and assumptions used during the analysis.

During the course of a failure analysis investigation, determining the mechanical properties of the failed component is often desirable or required. These properties include, but are certainly not limited to: tensile strength, yield strength, toughness, hardness, fatigue life, fatigue strength, and elevated-temperature properties. Also, though it is not a mechanical property, electrical conductivity of certain alloys may be determined. Evaluating mechanical properties can be done from either what remains of the failed component or from any exemplar component(s) that may be available. The failure analyst must consider how the post-failure test results may differ or vary from those of the original specifications at manufacture and attempt to minimize or avoid conditions that cause variation. There are numerous reasons why the specification or the manufacturer’s test data may vary from the mechanical properties data for the failed component.

This article addresses the causes of property variations, suggests methods to avoid or minimize their effect, and explains which data best represent the mechanical properties of the failed component. Factors that contribute to post-failure data variation are described, and specific test methods (i.e., tensile, hardness, fatigue, and fracture toughness) are discussed. Similar factors that cause variation occur in other test methods such as impact testing and stress-corrosion cracking tests.

Factors That Cause Variation
Some of the factors that may cause post-failure mechanical property data variation are:

1. Sample size (subsize)
2. Sample orientation and location
3. Sample geometry
4. Substitute testing methods
5. Test variability
6. Lot variability
7. Degradation of properties in service

Relevant Documentation
One of the first items sought in the investigation of a component failure is the relevant set of engineering drawings and design specifications, including changes. These may be difficult to acquire. Files may have been misplaced or discarded. The manufacturer may be unknown, may have gone out of business, and/or may be in another country and difficult to locate and contact. If the investigator is working independent of the manufacturer, the manufacturer generally will be concerned about maintaining the confidentiality of proprietary information. If a copy of the drawings is not available, the compo-
This includes hardness testing, electrical conductivity testing, atomic emission spectrometric testing, and energy dispersive spectroscopy.

Often, critical components are manufactured with raw materials purchased especially for the specific component batch and according to specific requirements set forth by the engineering specifications. Records of the material purchase can sometimes be linked to a particular batch of components. These records are kept throughout the manufacturing process and usually remain on file for a number of years. Raw material records may contain important information such as the composition and mechanical property test results from the foundry or other primary producer. Testing of material specimens after a component has failed will have much more significance if there is pre-failure data for comparison.

Again, these records may not be easily attained or may not have been required by the manufacturer or end-user. However, they could provide invaluable information in determining the failure environment and are worth the effort to investigate. Whenever possible, the raw material testing performed by the pri-