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ABSTRACT

Today, product liability cases seem to be increasing rapidly in both number and extent of liability of the manufacturer. Where analysis of defects and failures was once of interest to the enlightened company, it could well become a necessity for survival of all in the future. The materials engineer is likely to find many opportunities for displaying his prowess in this field. A course in Analysis of Defects and Failures was started in the fall of 1970 for senior mechanical engineering students at Worcester Polytechnic Institute (Massachusetts). Students helped prepare the course outline, which is included. The course presents unique opportunities for drawing together all of a student engineer's talents and training. A separate course in microstructure analysis has been developed and is recommended as background for the one in "defects." Students are given a list of the course objectives. The topics discussed are listed. The last few weeks of the course are devoted to group work in the analysis of a real failure. (LS)

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"ANALYSIS OF DEFECTS AND FAILURES - A MATERIALS COURSE FOR ENGINEERS"

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INTRODUCTION

Failure analysis is certainly nothing new to engineers and engineering. Any industrial concern which has its own future at heart looks searchingly at its mistakes and shortcomings with the intention of improving performance. Everyone can learn from his own mistakes; if anyone does not, he is certain to repeat those mistakes again and again. The philosophy of statistical quality control taught many of us years ago to analyze our "out-of-control" points. In a very real sense, failure analysis accomplishes a similar objective.

The author's own particular interests have led to the development of a course in "Analysis of Defects and Failures" at Worcester Polytechnic Institute. These interests, however, go back to the early days of statistical quality control in the U.S. Steel Corporation where the Metallurgy Department was responsible for quality of all outgoing product. As a novice metallurgist, he was given all the little problems of customer and interdepartmental complaints - broken springs, seamy wire, flat strip that split during heat treating, stock that "broke like glass" during bending, austenitic stainless steel that was not stainless, free-machining steel that chattered in automatic screw machines, and on, and on. Later, he had the privilege of being a student of Eugene P. Polushkin, then an elderly gentleman serving as Adjunct Professor of Metallurgy at the Stevens Institute of Technology. Polushkin had spent a lifetime investigating metallurgical failures and classifying them into the material which resulted in his book, "Defects and Failures in Metals". The notes and sketches made while a student in Polushkin's course bear a striking resemblance to the text of that book.

Probably most engineering faculty have at least had the opportunity of becoming involved in a number of miscellaneous investigations, complaints, and litigations where products or materials have failed. Today, product liability cases seem to be increasing rapidly in both number and extent of liability of the manufacturer. Engineers in the formerly "faceless" corporations are being identified, we are told, and charged by the courts of the United States with responsibility for their work. Where analysis of defects and failures was once of interest to the enlightened company, it could well become a necessity for survival of all in the future. The materials engineer, or any engineer with a strong materials background, is likely to find for himself many opportunities for displaying his analytical prowess in this field.

WHAT GOES INTO FAILURE ANALYSIS?

While the foregoing discussion may suggest one or more valid reasons for a course in Failure Analysis within the Materials curriculum, it does not present the whole case. Educationally, the material presents unique opportunities for drawing together all of a student engineer's talents and training.

Typically, a given "case" may call for the use of any combination of the following tools of the Materials Engineer:

1 - Optical Examination

a - naked eye and low-power macroscopes

b - microscopes; optical and electron

c - X-ray radiograph

d - crack detectors

2 - Mechanical Testing

a - hardness testers; standard, superficial and micro

b - impact tester

c - tensile tester

3 - Chemical Analysis

a - wet chemical

b - X-ray fluorescent

c - electron beam microprobe

d - X-ray diffraction

Knowledge of almost any topic within the Materials Science and Engineering area may be called upon in any given problem. Particularly prominent, certainly, are

Ductile and brittle fracture, fractography, fatigue, wear.

Materials Processing; welding and joining, casting, machining, forging, injection molding, cold forming, powder processes, heat treating

Corrosion; galvanic cells, oxygen concentration cells, stress-corrosion cracking, etc.

Similarly, several areas of general engineering such as the following are frequently germane to a failure analysis:

Mechanics of Materials; Stress Analysis

Dynamics and Kinematics of Mechanisms

Optimum Design

DEVELOPING A COURSE IN ANALYSIS OF DEFECTS AND FAILURES

In the Fall of 1970, a class of Senior Mechanical Engineering students at WPI, already registered for this course, was asked by the professor to do two things:

1 - List what you would like to learn in this course. Be specific.

2 - As a group, prepare for me instructions as to how we should proceed from here to gain the knowledge you have suggested that you need to accomplish the objectives.

Having first answered request #1, they then produced the next thirty minutes, essentially the outline previously prepared by the professor. With a little discussion, the minor differences were reconciled and the following course outline adopted:

Student Outline

A - Microstructure Analysis

1 - Normal vs defective

2 - Laboratory techniques

3 - Classification of defects

Student Outline - Cont.

B - "Tools of the Trade"

1 - Capabilities of analytical tools

2 - Where to start

C - Types of Failures

1 - Recognition

D - Classification of Defects

E - Prediction of Failure

1 - Recognition of conditions

2 - Prevention - change of parameters

F - Case Histories

1 - Procedures followed

G - Practical Case

1 - "Let us do one"

Since that time, dramatic changes, known to many of us as "The WPI PLAN", have taken place on the Worcester Polytechnic Institute campus. Increased emphasis on self-learning, increased project activity and changes in the college calendar have all occured. Where we now operate on a seven-week term, problems in logistics and difficulties in background must be solved quickly.

The Materials group at WPI has developed and now offers a separate course in microstructure analysis. This course is strongly recommended as background for the one in "defects". Consequently, with no need for developing a capability in metallographic preparation and microstructures, the objectives in "Analysis of Defects and Failures" have become:

"To conduct an analysis of a failed specimen of metallic material and

a - to determine the presence and identities of macroscopic or microscopic defects and inclusions

b - by a logical procedure, to establish a reasonable cause of failure."

Students are told that they will need to have or acquire the following to accomplish the course objectives:

Skills Needed

a - An ability to use macro- and micro- scopes of various kinds and powers.

b - An ability to prepare metallographic specimens without destroying the evidence they contain.

c - An ability to use metallographs, universal mechanical testers, hardness testers, impact testers and various non-destructive testers; e.g., radiographs, dye-penetrant, etc.

d - An ability to recognize and identify foreign materials and processing inclusions in metallic materials.

e - An ability to recognize normal and abnormal microstructures; and to determine their identities.

f - An ability to apply a logical procedure to a failure analysis; taking into account all the evidence.

Progress through the course then follows a pattern of two lectures per week for about three and a half weeks during which time the topics discussed are:

1 - Discovering Defects; before and after service failure; use of analytical tools; gathering evidence; credibility of other observers.

2 - Interpretation of Evidence; analysis; hypothesis; defense of hypothesis.

3 - Sources of Defects and Failures; ingot and casting defects; inclusions and impurities; rolling and working defects; heat-treating failures; other processing defects; service failures.

4 - Case Studies

Concurrently with the lectures, students are expected to spend available time in reading references from a list of materials to be found on the WPI library reserve shelf and in examination of a collection of 130 defects and failures for which they are furnished with a "guide sheet". They are also expected to satisfy "skills needed" a, b, and c, if for some reason they do not already possess those skills. With three courses per term as a full load, students may reasonably be expected to devote ten to fifteen hours per week to these tasks.

The last three to four weeks of the course are devoted almost exclusively to group work in the analysis of a real failure. Students usually locate and provide the failures to be investigated. In general, the course is considered to be "fun"; students enjoy playing the detective, as do most of us. The motivation for arriving at a successful conclusion to a failure analysis is quite similar to that for solving a crossword puzzle. While students have a propensity for jumping to conclusions, as have some crossword puzzle "doers", the analysis is expected to culminate in a report which is to be judged on the basis of whether techniques of the course have been used to gather evidence, develop an hypothesis and to defend that hypothesis. Most students try very conscientiously to apply the techniques - a number succeed in doing just that while applying their backgrounds rather broadly and reaching a satisfactory conclusion to the analysis.

APPENDIX

LIST OF REFERENCES

1 - Structure and Properties of Alloys; Brick et al. (2nd & 3rd Editions)

Alloy systems; treatments; many good photomicrographs - especially in the 2nd. Edition. (McGraw-Hill)

2 - Metals Handbook (8th Edition); ASM

Vol. 1 - Properties and Selection of Metals. Good section on Cast Iron, including micros.

Vol. 7 - Atlas of Microstructures. Excellent micros of many different metals and alloys.

Vol. 8 - Metallography, Structures and Phase Diagrams. Major sections on metallographic practices, techniques and principles. Micros - Many; beautifully done. Phase diagrams.

Vol. 9 - Fractography and Atlas of Fractographs. Fracture analysis; light microscope transmission electron microscope and scanning electron microscope fractographs.

VOLUMES 7, 8, & 9 ARE MAJOR REFERENCES FOR THIS COURSE.

3 - Metals Handbook (1948 Edition); ASM

A classic which contains much basic material. Major sections on

Mechanical Testing (pp 85 - 140)

Non-Destructive Inspection (pp 141-159)

Metallographic Examination (pp 159 - 168)

Testing Ferrous Metals (pp 389 - 422)

Articles on

Non-Metallic inclusions in steel (p 445)

Causes of service failures (p 243)

Fine reference on all sorts of metallurgical data - such as etching reagents, treatments, properties.

4 - Defects and Failures in Metals; Polushkin (Elsevier Pub.)

Text material, micros, macros. Would make excellent text for this course, but has been out of print for some years.

5 - Interpretation of Metallographic Structures; Rostoker and Dvorak

Excellent micros with interpretive text material. Some less common structures and metals. Has been used as a text for part of this course. (Academic Press)

6 - De Ferri Metallographia, V1,2,3: Habraken, et al (W. B. Saunders Co.)

Major work on vast number of ferrous micros. An excellent printing job.

7 - How Components Fail; Wulpi (ASM)

Pamphlet on failures in machinery. Especially good on fatigue failures. Original articles in Metal Progress from September, 1965 through September, 1966.

8 - Failure Analysis; Fellows (ASM)

Proceedings of (papers presented at) ASM conferences on failure analysis. Material on fractography, theory and practice of failure analysis, prevention of failure through analysis, cases; total of nineteen articles.

9 - Principles of Metallographic Laboratory Practice; Kehl. (McGraw-Hill)

Specimen preparation, etching, microscopes, photography, macro-examination, hardness testing, metallurgical tests. Best metallographic laboratory book ever put out.