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"A Guide for the Forensic Engineer"

Presentation: "Who cares about metals?"
Guest Speaker – ASM Int'l Rocky Mountain Chapter,
November 6th, 2008, at Cinzetti's in Northglenn, CO

Abstract

Metallurgy is the science of metals. The behavior of metals can be predicted. Go ahead, introduce yourself as a "forensic expert". Now, prove it. The forensic metals expert must exhibit excellent knowledge and communication skills to argue the case before peers, as well as a pleasing demeanor toward the authority who will render a verdict on the findings. The expert must supply a curriculum vitae, methodology, photographs and testimony to convince an audience about the facts in the case.

Metal failures are not always just accidents or acts of God. The forensic expert deeply cares why a metal failed and knows how to study and examine a broken metal part. One test may be worth a thousand expert opinions. The forensic expert who does not study history is doomed to repeat it. The forensic expert uses many bits of practical information that are not found in handbooks or taught in classes. Practical education, experience and the truth continue to be the answers for long-term success of the forensic expert. Your audience cares about metal.

Introduction:

Go ahead introduce yourself as an "expert".
Who in this audience would be introduced as an expert? Let me tell you a bit about myself: PE, AWS-CWI, CWE, ASNT Level III, and the list goes on. My life is filled with experience 50 years, education, BS, MBA, MS, PhD.

Ok, Now, strive to live up to the introductory title and prove it.

Who decides that you are an expert?
There is a story about two men on an Alaskan fishing expedition to a remote lake with a gravel shoreline, while wading barefoot in the water, they realize that a bear has taken interest in them and begins to chase them. One stops to put on his boots, while the other hollers,

> "What are you doing? Run…….." The reply was,
> "I only have to outrun you and then I'll be safe !!!".

It is as simple as *be true to yourself*. If you are an expert on a topic, then you are. If you are not, then just say so. Carefully select your topic. It is acceptable to reply "*I don't know*". If you don't know the answers, then perhaps you can find out.

Nowadays, the recognized Forensic Expert probably has a background, education, training and a recognized academic degree from a prestigious university.

Many PE registrations are just PE, except for Civil Engineers – Structural. The registration law permits the practicing PE to determine areas of personal competency and provide services accordingly. Be Ethical, and be true to yourself.

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For this ASM audience I'll define Forensic Expert as: the investigation of materials, products, structures or components that fail or do not operate/function as intended, causing personal injury or damage to property.

Failures may be from man-made catastrophes, operating error, equipment malfunction, or natural disasters. Forensic Experts are confronted with today's new and unproven computer designs and service life extensions of our aging infrastructure.

The consequences of metal failures may be significant or insignificant. The purpose of a Forensic Expert investigation is to locate cause or causes of a failure with a view to improve performance or life of a component or to assist a court in determining the facts of an accident.

You can surf the internet and find many who hold themselves out to the public as a forensic metals expert. What's the difference between a Professional and an Amateur? ETHICS, TRUTH and MONEY.

How does a client select an expert? Who does the client trust to not have a conflict of interest and present an unbiased and objective report of investigative findings?

Methods of Forensic metal investigations include:

- FOCUS on the specific metal failure.
- "reverse engineering", CHOICES made by the originators of the item.
- personal inspection of the part and surroundings for trace evidence, use a good LIGHT.
- statements from eye-witnesses of the incident, Communicate with proper DEFINITIONS / Terms.
- a working knowledge of current standards, Study in a metals LIBRARY.
- a case review of similar failures, Study HISTORICAL RECORDS.
- accident reconstruction, what really could have happened?
- examination of the subject failed component and an exemplar item, TALK to the failed part.

Forensic Metals Experts care why a metal failed.
Today, with computer modeling, more than ever there is a need for companies to use a Quality Management System and test metals to confirm reliability per specified properties.

When I came into the metals business, offshore, 3/8" thick plate, angles, channel or beam flanges were minimum. No particular need to be concerned about a metals strength or corrosion, there was plenty of "meat" to withstand most forces encountered. If in doubt, use ½" or larger. Things are different now.

Famous Engineering Catastrophes and Metals Investigations include the causes and effects of major accidents:

- the Challenger Space Vehicle that disintegrated upon re-entry to the earth's atmosphere
- the catastrophic Space Vehicle launch attributed to o-rings on the fuel container
- the loss of the RMS Titanic ship, brittle fracture theory
- Semi-submersible oil rig (Alexander L. Kielland) collapse from fatigue failure at the toe of a fillet weld in a diagonal brace.
- Offshore platform (Piper Alpha) in water depth of 474, experienced an explosion, fire during a safety audit.
- Liberty ships during WW II
- Bridge failures
- Water heater boiler explosions – beginning of the ASME boiler and pressure vessel rules and regulations.

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Forensic Experts know:

- Investigations
- Analysis
- Reconstruction
- causality
- prevention
- risk
- consequences
- legal aspects of the failure of man-made engineered products
- How to use a camera and take proper photographs
- How to write an expert's report of findings.
- How to listen to questions and only answer the question in the legal framework for Product liability
- High-Quality Engineering Design: An elusive goal
- Legal implications of Codes and Standards for Manufacturers/Fabricators/Contractors
- Accident Investigation and failure analysis, Engineering Framework
- Background Research – documenting the incident
- Background Research: Documentary Evidence
- Measuring Material Behavior and Condition by Testing
- Modes of Failure - overload, fatigue environmentally assisted fractures, corrosion, erosion, high temperatures, irradiation, hydrogen-related, nonmetallic materials
- Simulations – experimental, theoretical and ergonomic
- Reconstruction, causality and recommendations
- Litigation, expert and attorney relationship, financial arrangements, preparation for trial, the trial.

Structural failures are not always just accidents or acts of God.
Metal failures are often the result of human errors originating from unrealistic delivery schedules, oversight, carelessness, ignorance or greed. With the advance of design sophistication and fast-track methodologies also came the proliferation of metal failures. Early savings in design and construction costs can easily boomerang as later and larger costs of repair and litigation. The vulnerable metal structures of the late 20th century can provide "bread and butter" to Forensic Experts of the 21st century.

Metal failures are receiving increased attention over the past 30 years, primarily because of concerns related to public safety and equipment reliability. In addition, metal failures have a strong impact on economic changes and pressure exerted by expanded competition on the global market. In the United States, increases in litigation have forced commercial entities to investigate metal failures and identify the root causes to avoid repeated events and potential liability. It is a common statement in industry that a metal was intact and fully met the designer's specifications until the fabricator performed welding on the metal.

Considerable developments in failure analysis techniques and reliability are emerging with legal community acceptance of new methodologies in metals alloy analysis, fatigue, fracture mechanics and metallurgy. Actual metal properties can be determined without affecting an in-service component's integrity through portable alloy analysis, infield metallography and hardness testing. Laboratory optical emission spectrometry (OES) techniques provide reliable metal alloy determinations. Mechanical tests assess changes in metal bending and tensile properties, toughness, and metallurgical grain structures. Nondestructive tests provide accurate surface and sub-surface flaw detection and defect sizing. Metal life prediction and fitness-for-service analysis are achieving wider acceptance by the engineering profession and legal community. The economic advantages of avoiding business interruptions, extending equipment

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life and saving time required to build replacement components justifies the use of advance Forensic Expert metal examination techniques.

Owners, purchasing agents, attorneys and in-experienced project managers don't understand the factors and conditions that have lead to past metal failures. After a failure occurs, there is a "hurry-up meeting", examination of a dirty metal piece, and a resounding question, "Why did it fail?"

The Forensic Expert knows that specifying the correct metal and joining process is a fundamental choice by the designer. Bosses make decisions about the resources allocated for metal acquisition, identification and control. The quality assurance employed to track metals through fabrication processes depends upon the consequences of a metal component failing as a traceable result of using an incorrect metal. To protect the public, final product validation often requires a corporate official to sign-off, certifying that all metals used in a product are correct. This can merely be a token gesture. The Forensic Expert knows that metal alloy verification by an independent laboratory testing is the only sure way to confirm the type of metal that was used.

Many experienced engineers know that a great deal of important information and failure experience is locked up in the engineering files of companies fearing adverse publicity of their products. This is unfortunate since this unavailable data could be a great benefit to future engineering designers, metal selection considerations, fabrication techniques and general "know-how".

Metals are classified by many ways, including appearance, dimensions, weight, magnetic properties, chemical composition, mechanical properties, thermal coefficients and electrical conductivity. There are numerous accepted methods used to select and identify metals.

Numerous types, grades and classes of ferrous and nonferrous metals are available in industry. Potential defects are inherent in metals. Failures have occurred in all types and shapes of metals and will occur again sooner or later. The same causes and failure mechanisms may apply just as much to a ferrous metal as to a non-ferrous metal. The Forensic Expert must study the metal and interpret the conditions involved in each metal failure. Determination of the crack initiation site, propagation driving forces, or type of corrosion conditions are common elements of a Forensic Expert's analysis of a failed metal. The Forensic Expert knows that though the failure was in a pipe, ship, bridge or airplane, similar metal analysis techniques may be applied to evaluate the failure event.

Fatigue of metals refers to changes in properties resulting from the application of cyclic loads and encompasses many engineering disciplines. Fatigue of metals is a major area of scientific and applied research. The word fatigue originated from the Latin expression fatigare which means "to tire". The word fatigue is commonly accepted to describe an individual's physical or mental weariness. Now the term, fatigue, is widely accepted terminology in engineering vocabulary for the damage and failure of metals under cyclic loads. Fatigue applies to changes in properties which can occur in a metal due to the repeated application of stresses or strains, although usually this term applies specifically to those changes which lead to cracking or failure. There are many forms of fatigue. Several these terms are: mechanical fatigue, creep-fatigue, thermo-mechanical fatigue, corrosion fatigue, sliding contact fatigue, rolling contact fatigue, and fretting fatigue.

The field of fracture mechanics was virtually nonexistent prior to the mid-1940. The topic of fracture mechanics may emphasize material testing as well as mathematical derivations. A few practitioners address microscopic aspects of fracture, but most engineers use continuum models. The Forensic Expert is generally interested in the comprehensive treatment of fracture mechanics that appeals to a wider audience. Fracture mechanics includes several topics. A few of these are: dimensional analysis, linear elastic and elastic-plastic considerations, single–parameter assumptions at the crack tip, prediction

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of crack behavior, fracture toughness, crack propagation and arrest, creep crack growth, micro-mechanisms and material properties, fatigue crack propagation, environmental cracking, stress intensity, and J integral.

Metallurgy is the science of metals.
The behavior of metals can be predicted. Forecasting the internal actions of metal (steel) during thermal cycles and welding is common. Metallurgists can predict what metal will do as it is heated, cooled and welded. Metallurgists are challenged to increase the strength of a metal without also increasing the metal's brittleness.

Steel is a metal that contains alloying elements, which are added ingredients within an iron matrix. Most of the alloying elements are added to the iron in small amounts, but these alloying elements have a tremendous effect on the final properties of the steel. When alloying elements are added to a metal matrix, the metal's properties are enhanced without decreasing other desirable properties.

The ability of the metal to be welded in a production environment, with mechanical soundness and the serviceability of the resulting weldment is affected by the metal alloying elements.
Most welding, brazing or soldering processes require metallurgical compatibility that can be achieved by using clean base metals, controlled thermal conditions, and the addition of filler metal by skilled personnel.

The Forensic Expert's discovery about the material choices available to the designer when specifying metals for a component is invaluable. The Forensic Expert's confirmation about the type of metal actually incorporated into a failed metal component affirms design considerations, exposes in-service conditions, as well as reveals flaws that became defects. Numerous catastrophes are the result of incorrect material in the product.

As a society, we must make progress and so we must pay the price of progress. We must accept the inexorably rising standards of metals technology and we must relinquish comfortable routines and practices rendered obsolete because they no longer meet the new metal standards. This is our never-ending challenge in our global metals economy. In warfare, it has been recognized in recorded history that the society who masters metal wins the battles.

The Forensic Expert knows to examine failed metals efficiently, consider the designer's intent and confirm use of the best suited metals and connections. The Forensic Expert also uses many bits of practical information that are seldom taught in schools or found in handbooks.

The Forensic Expert recognizes that the performance of any metal member of a structure is dependent on the its alloy content and section properties. When the design is based on the efficient use of these two properties, the material selection and connection methods must be functionally acceptable and reasonably conservative.

Loads create forces that must be carried through the structure the engineer is designing for suitable places of counteraction. The designer needs to know how to provide efficient pathways and this often requires the use of various connections. Loads in a metal designs are transferred from one member to another through joints and connections. Both the type of joint and the type of connection must be specified by a feasible design and accurately installed by the fabricator.

Long ago, designers worked empirically with fabricators, using past experience and a practical approach to designs with metal. This practice became self-defeating by invariably resulting in excessively heavy designs and high fabrication costs. Today, designs are based on computer generated calculations

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intended to maximize efficient use of metal properties. Engineered safety factor analysis methods are readily available to assist with the prediction of metal fatigue conditions and avoid metal fracture conditions.

The metals used in products and processes are described by a variety of standards and specifications. The Forensic Expert knows to look for quality deviations in all aspects of metal processing and fabrication. Tests and inspection methods are specified by mortals and may be totally irrelevant to confirming the suitability of a metal component for the intended service. The actual metal used in a product must achieve the designer's intent.

Applications of metal assessment models and computer simulations must fit real-world choices. The Forensic Expert knows to develop and study the computer analysis as well as consider the published, historical requirements for metals to determine quality, uniformity or interchangeability. These documents may be codes, standards, specifications and professional association with experienced Forensic Experts.

Common definitions for these documents are:

Code: A systematic statement of a body of law. Intended to be mandatory and a requirement by an authority having jurisdiction. A systematically arranged, comprehensive set of rules, standards and specifications for welding applications, published to secure uniformity and to protect the public. Established and enforced usually by a public agency. Consists of a set of conditions and requirements relating to a particular subject and indicating appropriate procedures by which it can be determined that the requirements were met.

Standard: A guide established by authority, custom or general consent as a model or example to be followed. Applies collectively to recommended practices, classifications, and methods for a welding process or applications. A standard may be a rule, which is a prescribed guide for conduct or action, an accepted procedure, custom, or habit having the force of a regulation.

Specification: a detailed precise, explicit presentation of something or a plan or proposal of something. Clearly and accurately describes the essential technical requirement for a material, product, system or service. It indicates the procedures, methods, qualifications or equipment by which it can be determined that the requirements have been met.

All metal used in commercial business must realistically address the designer's intent, the installer's capability, and comply with the codes, standards and specifications.

Practical education continues to be the answer to the success of every Forensic Expert. Continuing education is the only way to examine and confirm metal items in our global economy. To learn more about the metal failure experiences study the metal alloy analysis and mechanical test reports. Compare this data with codes, standards and specifications. The cost of education and field experience may be expensive, but the cost of ignorance is more.

The Forensic Expert gathers metal samples from the failure site or the failed component for independent alloy validation, nondestructive tests and mechanical tests. Comparison of a failed metal piece with the engineering design documents, specifications and material test reports often reveals clues to the cause of a metal's failure event.

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One test is worth a thousand expert opinions.

The Forensic Metals Expert knows and continues to learn about:

Mechanical Failure:
- Ductility,
- ductile fracture,
- fracture of brittle substances,
- thermal effects,
- origin and nature of non-metallic inclusions,
- cracks and crack propagation,
- strain energy sources,
- brittle fracture of metals,
- dynamic loading,
- embrittlement of steel at low temperature,
- improvements in steel quality,
- embrittlement during fabrication,
- embrittlement in service,
- embrittlement and cracking due to hydrogen,
- lamellar tearing
- explosions – behavior of hydrocarbon – air mixtures
- Confined spaces and underground hazards
- Natural disasters – earthquakes, tornadoes, hurricanes, seismic waves, tidal waves,

The Forensic expert in the USA must have background, education, experience and certifications.

Your concerns are:
- Safety during the investigation, your own personal safety
- Design criteria and considerations.
- Metals specification, selection and installation.
- Process qualification and performance
- Quality criteria comes from the designer

How technological changes affect safety for persons and property.
- Safety on construction sites
- Design
- Materials
- Processes
- Quality requirements
- Developments in steel making
- Improved metal quality – steel and aluminum
- Service live extension

Evidence shows that in most fields of human activity, and particularly those which are most advances mechanically, there is a general improvement of safety with the passage of time and a proportional reduction in the accident rates.

We cannot be complacent about the integrity of structures. Any accident is of most interest if you or a family member are involved in the occurrence.

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