MAI METALLURGICAL ASSOCIATES, INC.

Metallurgical Associates is an independent testing and consulting company providing a complete range of services in materials testing and manufacturing problem solving.

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METALLURGICAL MINUTES

Materials Testing and Engineering ■ Failure Analysis ■ Manufacturing Problem Solving ■ Physical and Chemical Analysis

Reverse Engineering

…How Did They Make That?

Have you ever wondered why a competitor's product performs more reliably than yours? Or sells at a lower cost? Or worse yet, both?

If a vendor who supplies a critical component "disappeared", would you be able to specify it for a new vendor and re-start your supply stream?

Are you entering a competitive market with limited R and D resources? Would you like your product development to begin at the current "state-of-the-art", rather than from square one?

These are some of the answers we provide to clients through "Reverse Engineering" analyses.

Reverse engineering, from a metallurgical prospective, is a process in which a component is "deconstructed" using a variety of analytical testing procedures. These procedures identify the materials from which the component is made, how it was formed, any processing that has been applied to enhance its performance, and the sequence in which this processing was applied. The end result of a proficient reverse engineering analysis is a "recipe", or formula, which can be followed to produce an identical component in both appearance and performance.

More Questions, More Answers

There are numerous incentives to pursue a reverse engineering analysis. Perhaps the most significant, in financial terms, is the evaluation of a competitor's product. A great deal of costly and time consuming research and development can be saved by identifying the answers a competitor has arrived at to economically achieve maximum performance from a component. An effective reverse engineering analysis can put your new product development starting point at the cutting edge of current industry standards. Your R&D budget can then be applied to refining and improving your product into the new industry leader. This is particularly significant in today's global market where imports may take advantage of materials and processes which are unfamiliar domestically.

Your company's product may contain vendor supplied components, but as far as your customers are concerned, it's all yours. That's a good reason to know exactly what you are getting and how it was made. Manufacturing is more unpredictable than it once was. Consolidation, relocation and offshore sourcing can mean vendor components are made by different people in different facilities from a different raw material stream. All too often, production of needed components can abruptly end. Reverse engineering of a sample from remaining inventory can ease the transition to a new vendor source.

The Story in the Part

But how can the processing history of a component be determined without specifications, processing records and manufacturing documentation? Actually, it's all there in the component. You just have to know where to look. A case study of a relatively simple component, a bolt, is described in the accompanying illustrations. The same principals apply regardless of the sophistication of the subject whether a lowly bolt or a gas turbine compressor blade.

Dimensions

The first step in reverse engineering the bolt is to determine its physical dimensions. Measurements indicate the threaded portion is 0.375 (3/8") inches in diameter and 0.750 (3/4") inches long. There are 16 threads per inch, equating to Standard 3/8-16 NC. NC equates to National Coarse, indicating coarse threads in fastener industry jargon.

The head is a 9/16" wrenching hex and exhibits 6 radial lines which identifies the bolt as a Grade 8 fastener as defined by SAE J429. The letters "JH" on the head identify the manufacturer.

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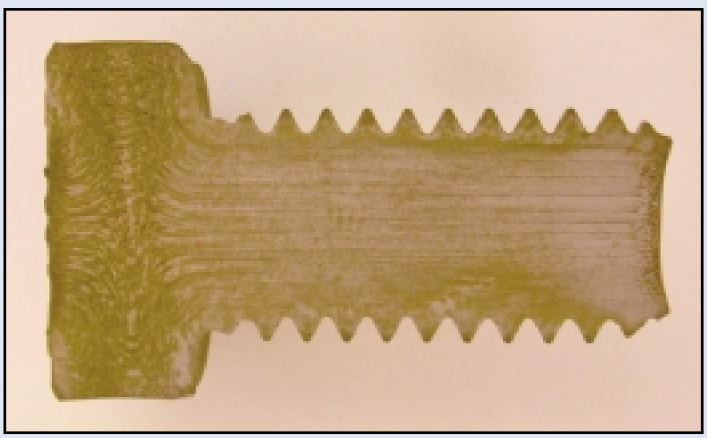
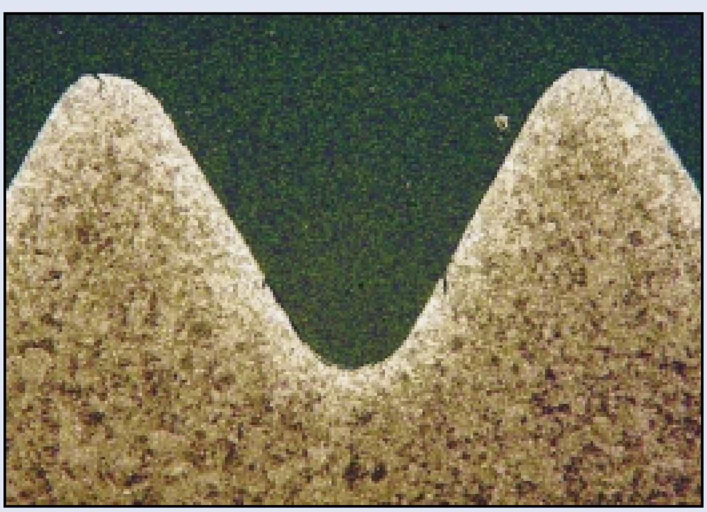
FABRICATION

We have now determined the dimensions and composition of the bolt. The next step in our reverse engineering analysis is to identify the process used to form the bolt into its present shape. How a part is formed-forging, casting, machining-can have a significant effect on its strength. We determined the forming method for the overall shape by cutting the bolt longitudinally in half, and aggressively etching the cut surface. Etching revealed "flow lines" showing plastic deformation in both the head and threaded shank of the bolt. These indicate the head was "hammered", or forged to shape by a process known as cold heading. Straight, aligned flow lines parallel to the threaded shank of the bolt indicate the original "blank" from which the bolt was formed was a cold drawn bar, one of the basic shapes in which steel is purchased from a mill. Examination of the threads revealed that these were roller into the shank rather than cut. Rolling imparts compressive stress which dramatically increases fatigue resistance in threaded fasteners.



"Flow lines" at the head and shank indicate the bolt was fabricated from a cold drawn bar. The hexagonal bolt head was cold forged, or, cold headed.

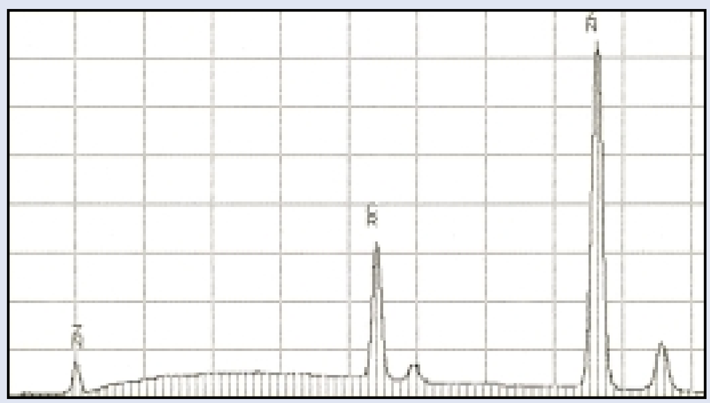


Examination of the threads in cross section shows that they are rolled into the shank rather than machined.

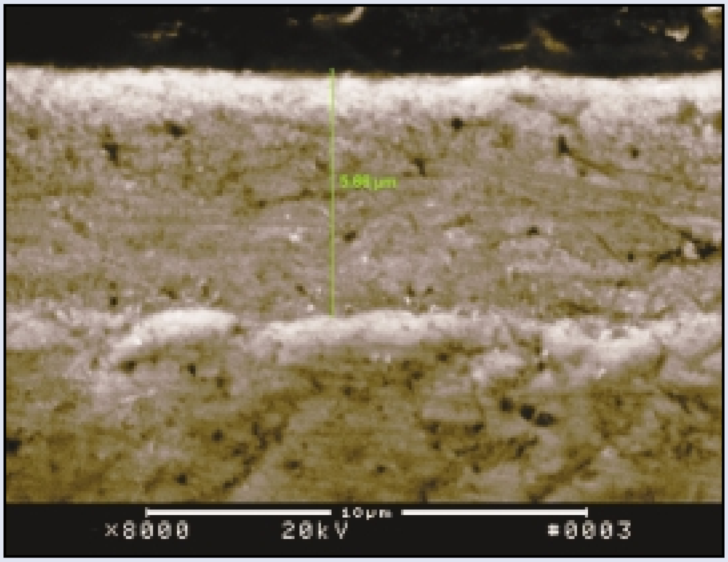
COATINGS

Coatings are applied to provide corrosion protection and to enhance appearance. In reverse engineering the coating on our bolt, the first step is to determine what the coating material is. This is accomplished using Energy Dispersive Spectroscopy, or EDS. This chemical analysis technique collects element specific x-ray emissions from a sample which are generated by the samples interaction with an electron beam. A Scanning Electron Microscope (SEM) is the typical source for the electron beam. These x-ray emissions generate a spectrum with peaks corresponding to individual elements. The application of this technique to the coating on our bolt indicates it is composed of zinc. A significant chromium peak is also present, which tells us that a chromate conversion coating has been applied over the zinc to further enhance corrosion protection.

The zinc plating thickness significantly affects corrosion resistance. To determine plating thickness, a polished cross section is prepared through the bolt and the plating layer is examined and measured at high magnification. The even outer surface and uniform thickness indicate that the coating is electro-plated rather than hot dip galvanized. The plating thickness is 0.00022 inches. Our reverse engineering analysis has now determined the coating is two ten-thousandths of an inch thick electro-plated zinc with a chromate conversion coating applied over it.



EDS analysis of the plating revealed zinc and chromium, indicating a zinc plating with a chromate conversion coating applied over it.



SEM photomicrograph of the plating cross section taken at 8000X. The green line indicates a plating thickness of 0.00022" (5.66 microns).

HEAT TREATMENT

Heat treating can make a dramatic difference in the strength and hardness characteristics of a part. Once the specific alloy is identified, as we did with our chemical analysis of the bolt, an evaluation of its microstructure and hardness will reveal the heat treating sequence which was applied.

The microstructure of the bolt consists of tempered martensite, which is uniform across the full cross section of the bolt. In SAE 4037 low alloy steel, this condition indicates that the bolt was heated to approximately 1550 °F and then quenched in oil which was heated to approximately 150° F. The use of heated oil reduces the quench rate in comparison to, for example, ambient temperature oil or water, and results in a more uniform microstructure over the full cross section of the bolt. Quenching results in hard, but brittle, properties. To retain hardness but reduce brittleness, and thereby increase "toughness", the bolt was then tempered. Tempering is simply re-heating of a part to a temperature below that from which it was quenched. The higher the temperature and the longer the time the part is held at that temperature, the more the brittleness will be reduced. However, tempering too long or at too high a temperature will nullify the hardness and strength imparted in quenching, so an ideal compromise is the objective. Hardness testing results, considered in conjunction with microstructure and chemical composition, indicate the temperature and duration of tempering. The hardness of the bolt, 39 Rockwell C, combined with these other factors, indicates a tempering temperature of approximately 1000 °F for two hours.

The microstructure at the forged head and rolled threads of the bolt is comparable to that exhibited at the core. This uniformity indicates that heat treating was performed after all forming operations.

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Reverse Engineering
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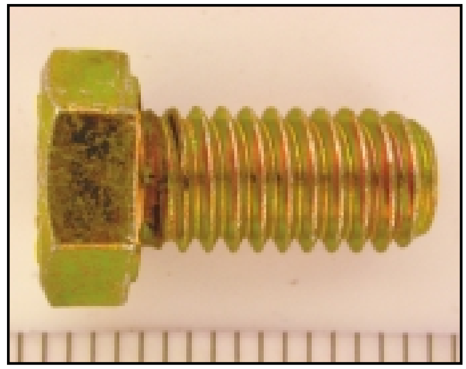
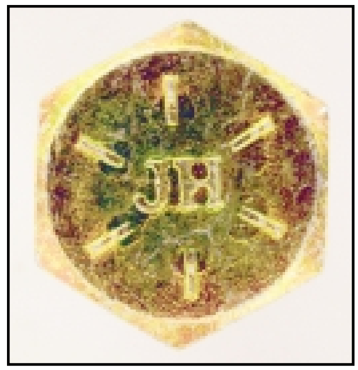


Macrophoto of the bolt showing Standard 3/8-16 NC coarse thread configuration.



Macrophoto of the bolt head exhibits six radial lines indicating it is a Grade 8 fastener per ASTM J429. "JH" is a manufacturer's mark.

Chemical Analysis

Identifying the material from which a component is made is, of course, fundamental to reverse engineering it. A variety of chemical analysis techniques are available which can determine the elemental composition of specific metal alloys, polymers, ceramics and composites. Analysis of our bolt was performed by Inductively Coupled Plasma Spectroscopy (ICP), a "wet" chemical analysis technique in which the sample is dissolved in acid and the acid is then passed through a plasma torch. The results of this process are "read" by the spectrometer with the results shown below:

Chemical Analysis

ELEMENT	BOLT	SAE 4037
Carbon	0.38	0.35 - 0.40
Manganese	0.82	0.70 - 0.90
Sulfur	0.009	0.040 Max
Phosphorus	0.007	0.035 Max
Silicon	0.21	0.20 - 0.35
Molybdenum	0.27	0.020 - 0.30

These results indicate that the bolt is made from SAE 4039 low alloy steel. The specified elements for SAE 4037 low alloy steel are shown above.

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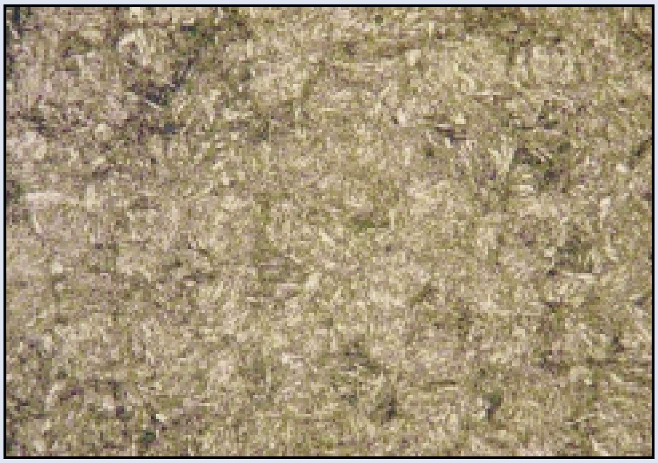

The microstructure across the entire bolt cross section is consistent with uniform tempered martensite, which in combination with the chemical analysis and hardness, revealed the heat treating processing.

THE FINAL ANALYSIS

Armed with these test results, we can now write a comprehensive specification with which we can manufacture a "clone" of our bolt. We could, of course, refine our specification with further testing. Tensile testing could be performed, but tensile values can be interpolated from the hardness values we've documented. Salt spray testing would define the number of hours of exposure in which plating integrity is maintained. However, this value can be predicted from the plating thickness and composition which we have identified. Our "spec" can be refined in greater detail as needed, however, with a concise series of tests we have identified all the fundamentals required to reproduce the bolt.

Obviously, a bolt in not a component that would typically be reverse engineered. We've used it as our example for two purposes. First, to illustrate that even a relatively simple component requires a defined progression of processing steps. Our second purpose is to place the emphasis on the process and principles involved in a reverse engineering analysis. Regardless of the complexity of the component, by following these principles, it can be reverse engineered.

Phosphate coating on steel substrate. SEM 7500X

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