

METALLURGICAL MINUTES

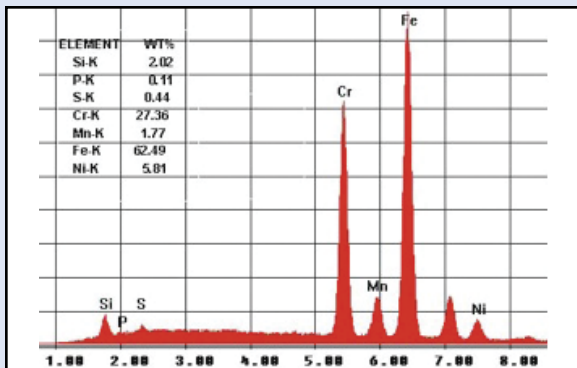
Materials Testing and Engineering - Failure Analysis - Manufacturing Problem Solving - Physical and Chemical Analysis

In The Works

We're often asked "What do you do?" If we hesitate to answer, it's because the variety of materials, components, and testing challenges is almost unlimited. A selection of recently completed analyses includes:

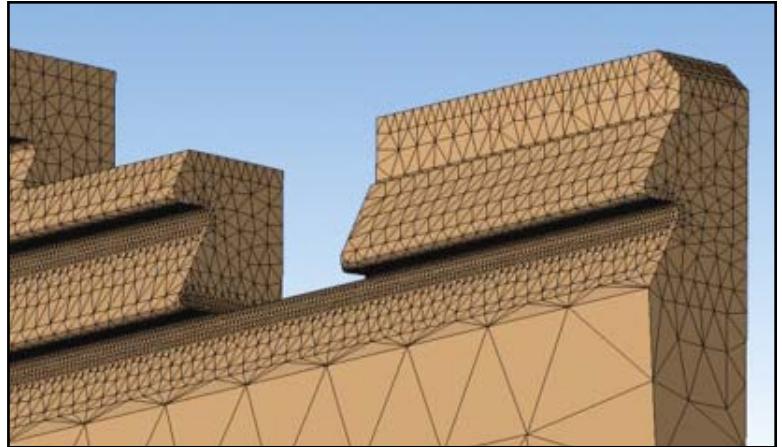


Our analysis of a failed municipal water utility pump and recommendations for material substitutions on critical components resolved costly service outages.



Analysis of discoloration on stainless steel tubing identified chromium oxide deposits had been rolled into the strip at the steel mill. After reviewing our report, the mill replaced the material and compensated our client for fabrication costs.

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MAI Finite Element Analysis Testing Your Product Before it Exists

Finite Element Analysis (FEA) is a numerical technique that simulates a component or structure's response to a wide range of stresses and conditions including loading, heat transfer, fluid dynamics and magnetic fields. In effect, FEA is capable of testing components before they exist in physical form. Think of CAD (Computer Aided Design) on steroids, where a "virtual part" that is designed using a computer is also tested by computer simulation.

FEA offers a number of distinct advantages by obtaining performance data in a shorter time at lower costs when compared to conventional research, design, prototyping, development and testing methods. These advantages include:

- 1 New designs can be simulated to determine their behavior prior to prototype fabrication and testing. FEA can not only "test" changes as a design evolves, but can also determine the affects of substituting different alloys or materials.
- 2 Existing components or structures can be modified, refined and tested in "simulated" form, shortening product development times.
- 3 Components or structures which have failed in service can be evaluated to determine the stress levels that they were subjected to at the time of failure. Potential design or fabrication improvements can then be developed from this data and "tested" by FEA to measure their anticipated performance.
- 4 Reverse engineering can be performed on existing components, identifying their load carrying capacity and other critical characteristics. These analyses require access to precise measurements of the component or structure.
- 5 Typically, CAD designs can be transferred directly to FEA systems for analysis, saving time and expense.

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MAI Finite Element Analysis

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How Finite Element Analysis Works

Breaking down the term “Finite Element Analysis” provides a good starting point in defining the technique.

Finite — In the analysis, the component or structure is divided into segments. By analyzing the effects of stress on small segments, rather than the complete component, the required mathematical calculations are simplified (relatively speaking). Ideally, the more segments the component is divided into, the greater the precision of the overall analysis when the results from each segment are compiled. However, there is a practical limit to the number of segments that can be analyzed. That number is **finite**, rather than infinite.

Element — The individual segments that the component is divided into for analysis are called **elements**. Data points are laid out on each element in the form of a grid, called the mesh.

Analysis — Mathematical calculations are performed to simulate the application of a range of stresses on the component. Further calculations determine the deflection of each element in response to the applied stresses. Additional calculations are then applied to compensate for the boundary, or “virtual interface”, between each element. This mathematically “re-assembles” the elements back into the whole component. The “boundary compensation” calculations are critical to the accuracy and precision of the analysis. Finally, these results are fed into a single large “master equation” which simulates the deflection response of the entire component to loading (stress).

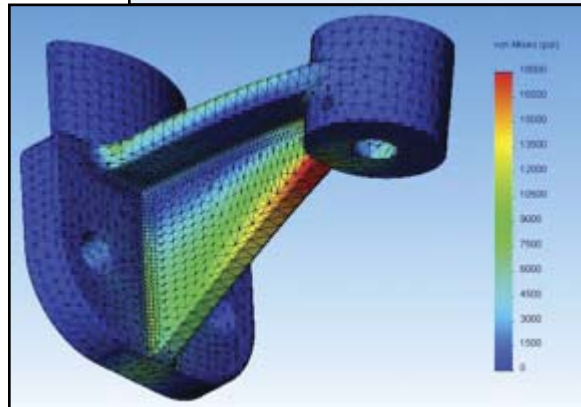
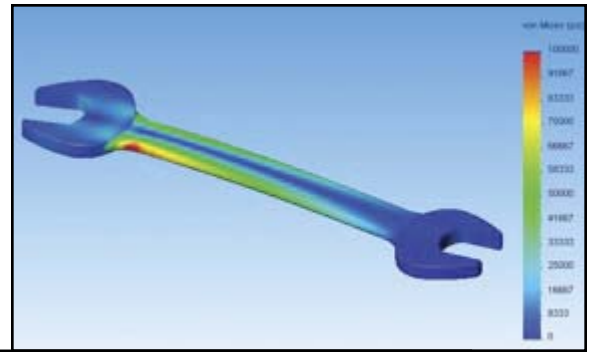
The Mesh

One of the single most important steps in the FEA modeling process is the configuration of the **mesh**. Intersecting lines of the mesh, called **nodes**, act as data locations for stress inputs, and measuring points for the deflection of the component resulting from these stress inputs. The mesh is programmed with the proposed alloy or material’s physical and structural properties such as elasticity, tensile strength, yield strength, etc.

Developing the mesh is a time consuming process. The mesh, and resulting nodes, are not evenly distributed across the modeled component. Instead, a “tighter” mesh and higher node density are assigned to critical locations on the component where higher stress levels would be anticipated in service. This provides a higher resolution of data from these critical areas. The mesh is more open with lower node density in less critical areas, reducing the time and complexity of the analysis. Typical high stress locations include corners, holes, fillets and notches. In analyzing an actual component that has failed, the failure location would be assigned a higher node density.

FEA In Action

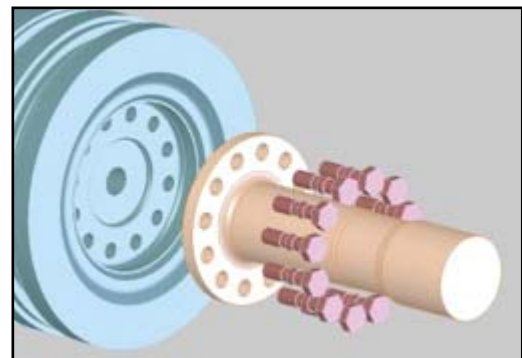
Finite Element Analysis can be profitably applied to a wide range of analytical questions, from the simple to the extremely complex. As a starting point in demonstrating FEA, let’s take



the simple open end wrench. In the view shown above, the wrench would be rotated counter-clockwise in use, with the distribution and magnitude of stress indicated by the color gradation. This identifies the area of greatest tensile stress (red) at the shank, just below the open end head.

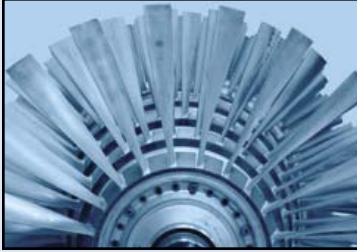
A common bracket design, shown above, further illustrates stress distribution and magnitude. In this image, the mesh is shown.

Proposed repairs of large, high value machinery can be evaluated by FEA before irreversible modifications are made. Cracks detected in the journal of a large gas turbine rotor shaft forging in service at an electric power utility provide an example. Replacement of the entire shaft would require a complete rebuild of the turbine, taking a significant percentage of electrical generating capacity off line for an extended time. FEA identified a less costly alternative that could be put in place far more rapidly. The proposed repair proposal called for cutting the cracked section from the shaft and replacing it with a bolted stub-shaft as shown below.

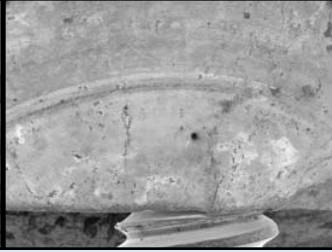


The practicality of this repair solution was verified by FEA of the stresses and strains on the stub-shaft and bolted joints (shown at the top of the back page).

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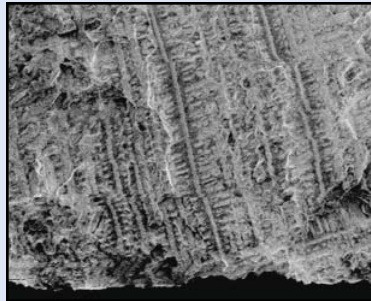
■ Our investigation of cracked blades from a land-based gas turbine, in service at an electric power utility, identified fatigue initiation sites at the attachment tangs. Suggested re-design of these attachments eliminated subsequent cracking and high cost failures.



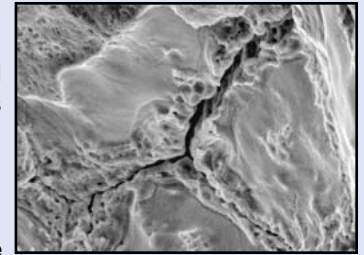
■ Failure analysis of stainless steel piping at a chemical processing plant identified stress corrosion cracking from chloride contamination. The contaminant source was identified and eliminated. Our analysis also noted weld defects unrelated to the failure and we provided weld procedure recommendations preventing potential imminent failures.



■ Our analysis of railroad maintenance tooling identified casting defects resulting from poor melting practices. The foundry compensated our client and implemented our recommendations, bringing subsequent castings into specification.



■ MAI supports our clients in legal and insurance actions as well as manufacturing process and failure analysis. Our work with a manufacturer of natural gas valves showed cracking to be the result, rather than the cause of a fire at a shopping mall.



■ Pre-production evaluation of an automotive camshaft to determine the off shore supplier sourced part was manufactured to specification. Our analysis confirmed chemical composition, heat treatment, hardness and case hardness, plating thickness and microstructure.



■ Our analysis of perforated stainless steel tubing runs from an evaporator revealed pitting initiated by micro-biological corrosion resulting from the by-product of several bacteria species. Recommended changes in the feed water prevented additional failures.



■ Our evaluation of the brazing process used in the production of heat exchanger cores enabled our client to fine tune manufacturing, increase through-put, reduce costs and improve quality.

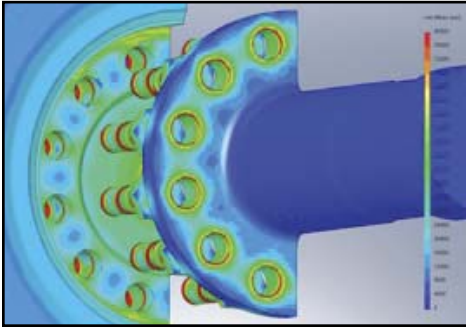
■ Our analysis of bearing failures in commercial refrigeration ventilation systems identified an inappropriate lubricant for the service environment as the root cause. A simple and inexpensive lubricant substitution ended subsequent failures.



■ Analysis of cracked tanker truck wheel studs identified fatigue fracture resulting from defects in the rolled threads. MAI worked with the stud manufacturer, revising their process and recertifying the product.

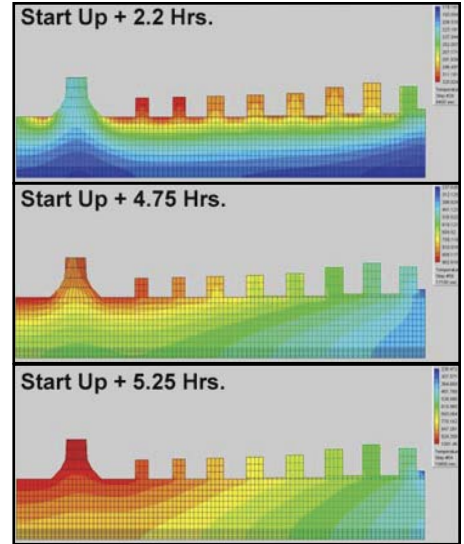
MAI Finite Element Analysis

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Heat transfer and transitions can also be determined with FEA models. Again, a gas turbine rotor provides our example, with thermal transients show to the right at 2.2, 4.75 and 5.25 hours from startup of the turbine. These analyses are used to optimize the duty cycle of the turbine, and illustrate the application of FEA to maximize operating efficiency.

The applications and precision of FEA have advanced rapidly with the progress of computational technology. However, the process is complex and requires great care in dealing with variables such as material properties, loads, and boundary conditions. Unknown variations in a component's service environment and maintenance add further complications. Because of these factors, conventional testing of finished components is still a prudent course to follow. But data obtained from FEA rapidly identifies significant design and performance parameters, avoids many design "dead ends" and reduces testing required to validate a design.



MAI provides Finite Element Analysis to serve our clients failure analysis, design, research & development and service efficiency requirements. Please contact Tom Tefelske, MAI Technical Director at (800) 798-4966 for further information on FEA and its potential to meet your specific requirements.

Metallurgical Associates Inc. is an independent materials testing and engineering facility accredited by the American Association for Laboratory Accreditation (A2LA-ISO/IEC 17025). Our expertise includes failure analysis, process problem solving and process/material certification and selection. For a quote or discussion of your analytical requirements, contact Tom Tefelske (tomt@metassoc.com), Dan Kiedrowski (dank@metassoc.com) or Rob Hutchinson (robh@metassoc.com), or call (262) 798-8098 or Toll Free (800) 798-4966. Visit MAI's web site at www.metassoc.com.

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