Weld defects and failures: quantifying fitness-for-service
How finite element mathematical simulations can mitigate risk and cut costs

Fatigue in welded steel components is often initiated by mechanical vibration, corrosion, and thermal cycling. Fitness-for-service analysis is the most viable step in determining the safety and financial risk factors related to component repair or replacement. This article shares insight about managing risk specific to weld failures.

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The predictive power of finite element mathematical simulations can often prevent the loss of millions of dollars in downtime, industrial catastrophes, injuries, and loss of life.

Cyclical stress factors
In materials science, fatigue refers to failures that result from cyclical stress. Most often, such failures manifest themselves in some form of mechanical or thermal fatigue, often as a result of vibrations, loading and unloading, or repetitive fluctuations in temperature. These failures are often blamed on the designer or fabricator, when the real cause is transient operating conditions. For instance, operators often increase applied loads and temperatures in an effort to increase productivity, as a result, they inadvertently push the limits of fatigue damage and increase the risk of failures.

As a point of reference, it is estimated that fatigue contributes to approximately 90% of all mechanical service failures. An increasing demand for high performance industrial systems has exacerbated the likelihood of structural fatigue.

Fatigue as the cause of weld failures
Weld failures present one of the most serious financial, safety, and reputational threats across many sectors including: chemical, petrochemical, aerospace, automotive, construction, and energy. Any component that exceeds its fatigue or endurance level can trigger a weld failure. They can occur suddenly, causing catastrophic failures that could have been prevented by prior analysis and repair.

The nuclear industry was the impetus to develop fitness-for-service (FFS) practices. In particular, the ability to quantify the tolerable results of weld defects played a key role in validating the safety of nuclear vessels.

Still today, however, few industries outside of chemical and nuclear are well-versed on the availability and exactness of FFS procedures. As a result, many companies fail to verify fatigue tolerance and safety margins before making the costly decision to replace components that are excelling surface damage.

By employing FFS measures, many companies could have the capacity to design and safely implement repairs to restore fatigue and fracture-safety margins, even given an operational environment of cyclical stresses. Making an informed decision to repair or replace the compromised component requires a multi-faceted investigation that yields quantifiable results.

Companies often opt for metallurgical analyses to evaluate and act in response to weld cracks. Metallurgical analyses are limited, however, and unlikely to address fatigue or fracture analyses. Without quantifying a component's integrity, decision makers are left to select a path of action based on an incomplete picture. Only in the presence of reliable data can the decision to extend fatigue life be made with confidence.

The predictive power of mathematical simulations and fatigue evaluations
Modern materials science and mathematical simulations provide the most robust method of evaluating FFS. Finite element analysis is a scientific process that integrates engineering principles and mathematical physics. As the name implies, finite element analysis divides the entirety of a complex structure into multiple and precise elements. This exercise identifies what occurs under various conditions of cyclical stress and allows for accurate predictions about future cracking.

Mathematical finite element simulations are able to quantify stresses, even with increased operating loads and the reduction in brittle and ductile fracture margins that arise from higher applied static and dynamic loads. Simulations are also used in quantifying the reduction in fatigue life due to an increased number of operating cycles, as well as the relationship between fatigue initiation and aggressive operating conditions. Also of importance, mathematical finite element simulations can confirm whether stress limits meet industry codes and standards.

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This heat exchanger exhibits multiple cracks at the flange bolt holes because design did not accommodate wear thermal expansion.

Figure 1: Design fatigue curves for carbon, low alloy, service 40X, high alloy alloy, and high tensile steel for temperatures not exceeding 392°F (200°C).
When is fitness-for-service the right choice?

Two circumstances often present companies with the need to conduct a fitness-for-service (FFS) evaluation: when components are used to quantify and predict continued service, and when the residual life of an in-service component must be assessed beyond the original design life. In both cases, the decision to repair or replace is critical to the reliability and integrity of the equipment.

Specific to weld failures, FFS evaluations can demonstrate the structural integrity of tanks, vessels, and other components. In many cases, however, repairs are not an option, so they replace damaged components. In some cases, however, repairs are feasible. The decision to repair or replace an in-service component can be guided by finite element mathematical analysis.

Capturing the value of FFS

Most companies are stretched to the limit in terms of production, decrease costs, and ensure safety. Unfortunately, fatigue failures are too common, and they work against a company's objectives. Decision makers must carefully navigate the risk and expense of failures.

FSF evaluations can quantify and demonstrate the ability to extend service life and avoid the costly process of replacement. FFS evaluations often reduce maintenance and operating costs as well, which is one reason why companies can gain in today's competitive marketplace.

References


About the author

Dr. William J. O'Donnell is the founder of O'Donnell Consulting Engineers, Inc., a firm that provides failure causation evaluations in state, federal, and international courts. He established O'Donnell Consulting Engineers in 1996 after 35 years in the testing and engineering renovation field. He has published more than 100 technical papers related to stress analysis methods, design of equipment, and safety. He is the author of many books and is an expert in the field of fatigue analysis.

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