

# Addressing Stress Corrosion Cracking in the Turbomachinery Industry

**Stress Corrosion Cracking is a common problem affecting turbomachinery components such as rotor discs, steam turbine blades and compressor impellers, and is a major factor driving component repair. This type of cracking may lead to catastrophic failures which result in unplanned down time and expensive repairs. A comprehensive root cause failure analysis is always needed to determine and confirm the root causes. Based on the findings of the analysis, different methods can be used to alleviate the cause of stress corrosion cracking. The design of the component, operating environment and other factors should be considered when selecting a method to mitigate stress corrosion cracking.**

## Introduction

Stress corrosion cracking (SCC) is a failure that occurs in a part when the following conditions are met:

1. An alloy is susceptible to stress corrosion cracking
2. Corrosive environment
3. Sufficient level of stress

At Sulzer we have analyzed multiple cases of stress corrosion cracking on turbomachinery parts such as steam turbine rotors, steam turbine blades, shroud bands and compressor impellers.

Sometimes we work with equipment where failures have already occurred. Before repairs can be performed, it is necessary to understand the root cause in order to prevent failures from re-occurring. In these cases, care must be taken to preserve any evidence so a proper metallurgical evaluation can be performed.

In other instances, the equipment that came out of the service without any perceived issues is undergoing a routine incoming inspection. During it every rotating and stationary component goes through non-destructive testing (NDT) to identify defects. If defects are found, a metallurgical evaluation is used to determine how the defects originated, propagated and if they occurred due to SCC.

## Metallurgical Identification of Stress Corrosion Cracking

In most cases, full destructive metallurgical failure analysis is needed to determine the root cause if an existing crack propagated due to SCC. Metallurgists will say that only through the evaluation of the fracture surface and optical metallography the real root cause can be determined.

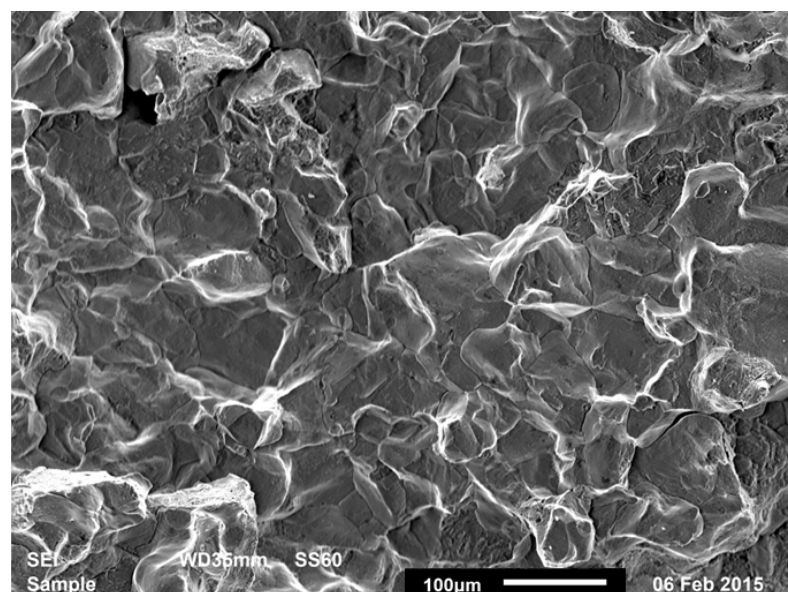
Depending on the base metal and corrosive chemicals in the service environment, stress corrosion cracking can propagate intergranularly or transgranularly. Intergranular crack propagation means the crack propagates along the grain boundaries of the base metal, while transgranular propagation is when the crack propagates directly through the grains. Evaluation of the fracture surface with a scanning electron microscope (SEM) and optical metallography will help identify mode of crack propagation.

Figure 1 shows an SEM image of a fracture surface exhibiting intergranular mode of propagation on an integral disk of a steam turbine rotor.

Care should be exercised when attributing an intergranular mode of propagation to SCC since there are other failure mechanisms (such as creep) that lead to an intergranular mode of failure.

Branching of a crack is another common characteristic of SCC and optical metallography through a fracture/crack will help identify this feature. Both modes of propagation can exhibit crack branching. An example of branched intergranular cracking is shown in Figure 2. Similarly, optical metallography through a fracture surface may also show branching of transgranular cracks.

Once the mode of propagation has been identified, the next step is mitigating the cause of propagation.



**Figure 1: SEM image of a fracture surface showing intergranular fracture due to stress corrosion cracking.**

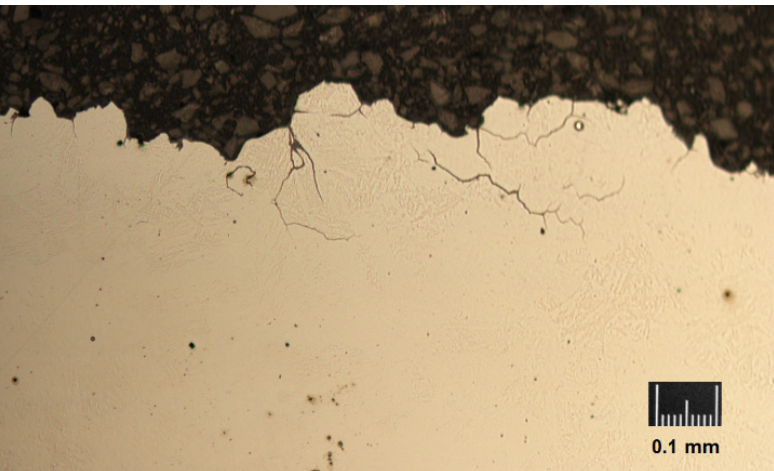


Figure 2: As-polished cross section through a fracture surface showing branched cracking due to stress corrosion cracking.

### Mitigating Stress Corrosion Cracking

Once it is confirmed that stress corrosion cracking was the mode of failure in a component, different approaches could be employed to mitigate the issue. The approaches include evaluating and potentially modifying the service environment, base metal and reducing stress in the component.

Identifying the corrosive agents in the service environment has to be done when evaluating their impact on the base metal and before taking actions to address their presence. This is important since certain chemicals are known to cause SCC in particular alloys. For example, nitrates are known to cause SCC in low carbon steels, but not in austenitic stainless steel. The chemical composition of the base metal can be checked to confirm its susceptibility to SCC. An energy dispersive spectroscopy (EDS) on the fracture surface helps identify the corrosive agents. The investigation can also include a full chemical analysis of the working fluid going through the machine. Lastly, a Copson curve can be used if a change of material is considered or to evaluate if the original base metal was a good choice for the application. For example, the Copson curve in Figure 3 relates the stress corrosion susceptibility to the Nickel content in stainless steels with Chromium contents greater than 16 percent.

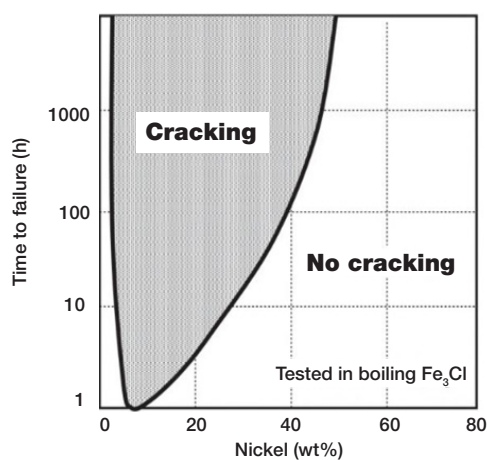


Figure 3: A sample Copson Curve [1] showing susceptibility of stress corrosion cracking in alloys with different amounts of Nickel.

It is always recommended that the number of corrosive elements and their amount be reduced or removed or from the working fluid. Otherwise, this information can be used if a change of material is to be considered or to evaluate if the original base metal was a good choice for the application.

In general, a highly stressed areas in the part are more susceptible to crack initiation and propagation. A highly stressed location that coincides with the crack can provide additional confirmation to the metallurgical finding that the crack propagated due to SCC. Calculating the stress at the crack's location, via finite element analysis (FEA) if necessary, will help determine if the predicted stress exceeds the stress threshold of the material required for SCC to initiate.

The following are methods for reducing the likelihood of cracking due stress concentrations:

- Modify the design of the component to reduce stresses
- Induce compressive stresses

A design modification can reduce the stresses below the stress threshold at the crack's location. However, care should be taken during the redesign process to avoid the possibility of trapping corrosive agents in enclosed areas. For example, tangentially-loaded blade roots can be redesigned to be axially-loaded which eliminates the possibility of corrosive agents to build-up over time. Surface treatments that induce compressive stresses also help mitigate a component's susceptibility to SCC. Shot peening, ultrasonic high frequency impact treatment, laser shock peening and low plasticity burnishing are some of the common surface treatment methods to induce compressive stress on the surface.

Each of these changes have its advantages and disadvantages so proper evaluation is needed when selecting a modification.

### Conclusion

Despite the advances in design and manufacturing, turbomachinery components are exposed to extremely harsh environments on a daily basis which causes them to experience stress corrosion cracking. Metallurgical root cause failure analysis is needed to confirm if a crack/failure was related to stress corrosion cracking. There are multiple ways to mitigate stress corrosion cracking, such as removal of the corrosive elements, design modifications to reduce local stress, surface treatments to induce compressive stress or upgrading the materials used. However, a deep understanding of material selection and comprehensive structural analysis of the part is required when determining the best approach to mitigate the stress corrosion cracking depending on the chemicals present in service environment.

### Reference

Graphic is based on:

- [1] Lippold J C, "Welding Metallurgy and Weldability", pg: 278, 2015