New welding material for repairing turbines

Steam turbines are used across the world as a source of power for many different industries. Even with the best preventative maintenance procedures and techniques, problems can still arise. Resolving one of the more serious issues, that of stress corrosion cracking, can often be achieved in a straightforward manner by accurately identifying the causes and taking the appropriate corrective action. Sulzer's new weld repair using 12% chromium steel can give renovated rotors an extended life over the original material.

Older steam turbines are prone to stress corrosion cracking of the turbine blades, disks and other components. Understanding the causes and potential solutions can help to minimize downtime and improve reliability. Sulzer's "forensic" engineers not only evaluate the nature of the cracks but also calculate stress levels for the damaged parts with finite element analysis (FEA). In some cases, Sulzer went a step ahead and used a new weld repair method to increase the lifetime of the refurbished turbines tremendously.

Inspection methods for cracks

The sixth stage disk of an integral steam turbine rotor of a customer in India developed cracks in the root sections of the blade attachments. The turbine has an operating speed of 9'000 rpm, and the steam inlet temperature is 400 °C (750 °F). The equipment had been well maintained, and the service history was available to the maintenance engineers.

Usually, the root section of steam turbine disks and blades is subject to particularly high mechanical load. In this case, a total of seven roots with cracks were identified using a magnetic particle inspection process. The next step was to determine the cause of the cracks, and in-depth evaluations were carried out. First, four cracks were opened mechanically, and the fracture surfaces were examined using a scanning electron microscope (SEM). The SEM examination showed evidence of intergranular cracking.

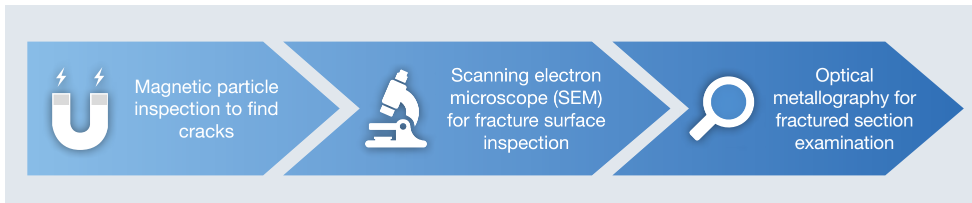

Fig. 1 Inspection methods used to analyze the cause of cracking.

In addition, the engineers (Fig. 2) used optical metallography to examine a section of the cracked area and found branched cracking immediately below the fracture surface. In conjunction with the findings from the SEM observations, the cause of the cracks was identified as stress corrosion cracking. There was no evidence that other fracture mechanisms, such as fatigue, had played a role in the failure.

Fig. 2 Sulzer's laboratory for metallurgic investigations in Houston, TX, USA.

Analyzing the material composition

Chemical analysis and testing of the mechanical properties of the components involved in the failure is very important. Optical emission spectroscopy was used to identify that the rotor was made of the low-alloy steel grade ASTM A470 Grade C. The mechanical properties were also tested, and only the tensile strength was found to be out of specification; in fact, the tensile strength was higher than the maximum value specified. Typically, this can lead to increased susceptibility to corrosion.

Further investigations were carried out using energy dispersive spectroscopy (EDS) to determine the chemical composition of the deposits at the fracture surface (Fig. 3). In addition to the elements that the engineers expected to find in the base metal alloy, the EDS identified sodium, magnesium, tin and chlorine. The most likely source of these elements is the steam used in the turbine.

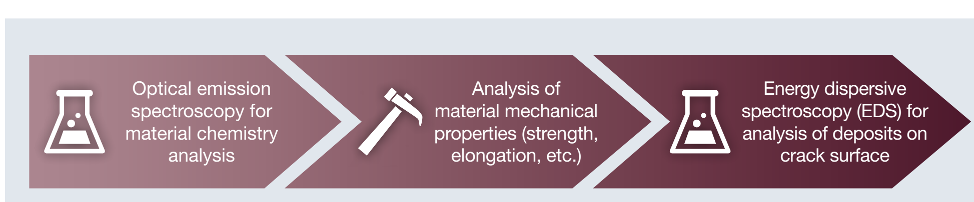

Fig. 3 Material analysis of cracked parts.

Structural analysis

The stresses at the crack locations were estimated using finite element analysis (FEA). This involved creating a 3D CAD model of the disk with the blades fitted (Fig. 4a). The FEA (Fig. 4b) assessed the stress values experienced by the disk and the blade at the operating speed of the turbine (Fig. 5). In this case, the equivalent stresses in the disk at the short blade root exceeded 689 MPa (100 ksi). However, the maximum stress value is 786 MPa (114 ksi), which is less than the measured yield strength of the material, 862 MPa (125 ksi). This provided further evidence that the stress did not cause the cracks due to yield, but rather, that the stress corrosion cracking was the primary cause of the failure.

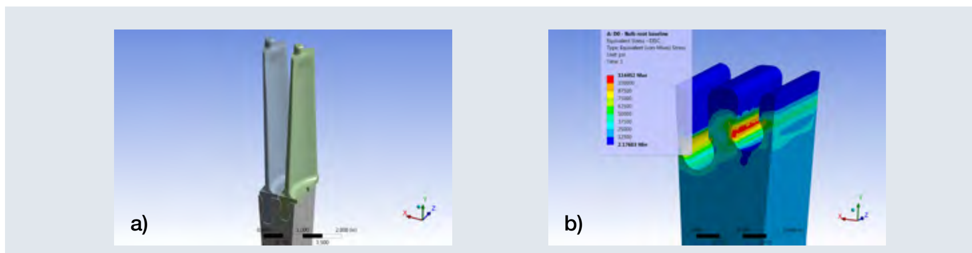

Fig. 4 Finite element analysis of a blade identified maximum stress levels at the operating speed.

Fig. 5 Design analysis of blades.

Evaluating the root cause

For stress corrosion cracking to occur, three conditions must be present:

- The alloy must be susceptible to stress corrosion cracking (1)
- The stress intensity factor must be above the threshold value (2)
- A corrosive environment must be present (3)

In this case, the higher tensile strength levels made the disk alloy more susceptible to corrosion (1). The location of the high-stress region (2) within the disk corresponded perfectly with the crack initiation and propagation locations found during the magnetic particle inspection (MPI). Finally, the presence of chlorine at the fracture site indicated a corrosive environment (3), which led to the cause of the failure being confirmed as stress corrosion cracking.

Reducing stress corrosion cracking

To avoid stress corrosion cracking, it is necessary to remove or reduce at least one of the prerequisite conditions. Modern steam turbine components use the latest alloys as well as different blade root designs. In this case, redesigning the blade root to reduce the peak stress levels would not be feasible because the current bulb (ball) root design is very compact and does not allow for much improvement in the stress profile. Here, protective coatings applied to the surface of the disk can provide robust protection against corrosive elements attempting to attack the base material of the rotor.

Another feasible solution for the owner of the turbine is to address the presence of corrosive agents in the steam. Conducting a complete analysis of the steam being used in this machine would allow the chemicals to be identified and would indicate subsequent actions that could be taken to improve the quality of the water treatment at the plant.

Investigation team at work

Another customer in the United States had a similar failure in one of their steam turbines. Cracks in the turbine's sixth stage disk root section were investigated using procedures similar to the ones described above. Again, the engineers of Sulzer's "failure investigation team" executed the chemical, mechanical, fractographic and design analyses. Apart from some minor variations in the chemical composition of the rotor, the measured impact strength value (Charpy impact test) did not meet the specified requirement for the alloy, and it was considerably below the limits acceptable for the subject alloy when used in turbine rotor applications.

Further investigation using an SEM showed that the entire fracture surface exhibited intergranular structure. An assessment using optical microscopy of a polished section that also indicated branched cracking supported this finding. In addition, an EDS analysis found heavy oxide on the fracture surface. All these findings confirmed that the failure had been caused by stress corrosion cracking.

After a polished sample of the fracture surface had been chemically etched, it became clear that the microstructure was not fully tempered martensite. This finding, combined with the low impact strength values, indicated that the forging had not been properly heat-treated, and the combination of these factors may have accelerated the crack propagation in the disk (Fig. 6).

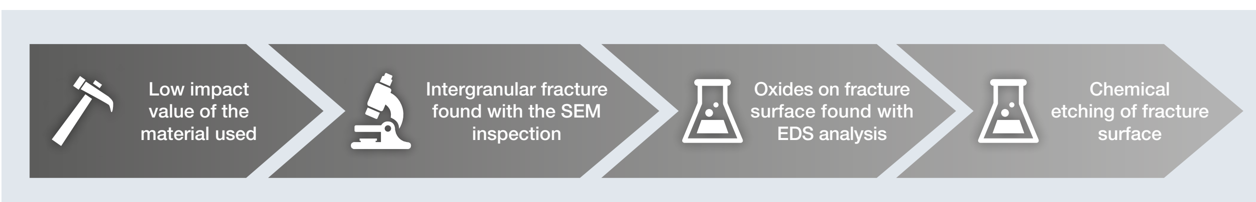

Fig. 6 Case-specific analysis and findings of cracks in the disk's root section.

How Sulzer developed a new weld repair

Getting to the root cause of the failure of a steam turbine component can take considerable effort and may require a suite of technical evaluations. However, this time will pay off generously as the performance and reliability of the turbine will be improved. The findings from a failure analysis may also be useful, and can be applied for similar components of different turbines.

The following section discusses a new weld repair process that can mitigate the stress corrosion cracking in turbine rotors. Though this repair process was not applied in the two above-mentioned cases, it would have been applicable to the two rotors as well.

Driven by steam from the inside of the earth

Geothermal steam turbines work with steam that may contain very corrosive components. These components vary unpredictably because of the nature of the geothermal steam. In practice, very substantial damage can occur over time due to corrosion and erosion, which can cause the areas exposed to the steam to be "washed away."

“ *The idea of using chromium in the welding process arose in 2013 when Sulzer in Indonesia received a geothermal steam turbine rotor repair project from a customer in the Philippines. The steam turbine showed cracks and stress corrosion. Our customer then requested improvements to avoid any recurrence in the future. The implementation of this new material for repair processes won the Sulzer Innovation Award in 2018.*

Hepy Hanipa, Head of Turbo Services SEA, Purwakarta, Indonesia

Fig. 7 Welding repair with 12Cr weld of a steam turbine at Sulzer’s Turbo Services center in Indonesia.

Sulzer’s new repair service

Original equipment manufacturers often propose replacing the rotors. However, the Rotating Equipment Services team saw a market opportunity to set itself apart by repairing the rotors by welding. Welding is less costly and can reduce the waiting time for clients. In this process, an area of damaged material is removed, and a large mass of weld material is deposited to restore it to the original form. After welding is completed, the part is machined to make the geometry of the renovated rotor identical to the original. This process can be much quicker than ordering a replacement part because the long lead time for new forgings can be avoided. Both the customer and Sulzer profit by employing weld repair processes.

Longer turbine lifetime with chromium

There was some concern within the Sulzer team about the weld material used at that time — a low-alloy weld wire for turbine rotor material, which is likely to suffer corrosion cracking when exposed to a hostile environment. The team eventually came up with the 12% chromium stainless steel (12Cr) weld wire option, which provides even better corrosion resistance than the original rotor materials in many cases.

The 12Cr weld has greater corrosion resistance than typical low-alloy steel rotor alloys. This means that, in some cases, the 12Cr weld can give the renovated rotor an improved life over the original material.

Applying a 12% chromium weld onto the various low-alloy rotor steel base materials is quite a difficult feat. Nevertheless, a welding process was developed successfully by the Sulzer engineering and operations teams (Fig. 7) and has already been implemented in the repair of rotors shipped to customers on-site.

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