Laser Welding to Industrial Gas Turbine Components

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Sulzer Elbar, a company of Sulzer Turbomachinery Services, is able to carry out laser welding of hot-section components of industrial gas turbines with low distortion, allowing near-net-shape component reconstruction. Defect-free welds can be produced, even when similar or identical filler metals are used. In suitable areas of components, the grain structure and orientation of directionally solidified (DS) and single-crystal (SX) base materials is continued in the weld deposit.

The repair of hot-section components is an established service provided to the users of heavy industrial gas turbines. Although repetitive repairs can be automated effectively, the large variety of shapes and sizes of heavy industrial gas turbine components calls for manual weld repairs.

Throughout the industry, many different types of welding are used, including the widely employed argon arc and (micro-)plasma welding. Weld filler metals are usually solid-solution-strengthened alloys, selected for good weldability and corrosion resistance rather than for creep resistance.

Laser welding is just one of a number of welding processes used for joining or restoration. Due to the concentrated heat input, laser welding introduces notably less distortion compared to most other welding processes. Until recently, there was little need for the development or introduction of laser welding, since most damage to components occurs in areas of low stress and alternative, highly creep-resistant surface build-up repair processes are available. Especially for gas turbine blades, damage caused by increased thermal-stress levels and the introduction of new types of base materials created a need for better weld filler metals and better technologies to apply them.

In low-temperature applications, results from laser welding of conventional weld filler metals are comparable to results obtained by other welding processes. In high-temperature applications, results differ as will be described below.

Strength of Superalloys

The materials that are used in heavy industrial gas turbine hot-section blades are nickel base superalloys. Apart from the alloy composition and the structure of the phases formed by heat treatment, large grain size and grain orientation contribute strongly to creep resistance and thermal-cycling resistance.

In recent years, highly creep-resistant, coarse-grained, equiaxed cast structures have been replaced by DS and SX alloys. Both have superior properties, but only in one orientation. Compared to conventional materials, the weldability of these new materials has not changed: repair welding can still be carried out using conventional, well designed welding and heat treatment processes.

The larger mismatch, however, between the properties of conventional weld filler materials and state-of-the-art DS and SX alloys creates the need for both better weld filler metals and technologies that can be used to apply them. Ideally, weld filler metals are identical in composition, structure, and grain orientation to the alloys on which they are applied.

1 The leading edge of an equiaxed (conventional) cast blade – a high-stress area – is being laser-welded with highly creep-resistant filler metal.

Conventional DS and SX Welding Research

Much laser welding research was driven by the need to develop repair processes for DS and SX materials. Focus is placed on the continuation of the DS or SX structure from the base material into the weld deposit while using similar or identical filler metals. As a result, laser welding parameters for the production of these metallurgical structures are well known.

When welded on a laboratory scale, DS and SX structures can be continued in the weld filler metal without major problems. With this know-how, it is possible to weld blade tips, seals, and other simple geometries, producing similar properties in the weld deposit material as in the base material. In these areas, laser welding is only an alternative to manual argon arc or (micro-)plasma welding, producing similar equiaxed weld filler metal deposits.

Laser Weld Repairs

Laser weld repairs may thus challenge conventional argon arc or (micro-)plasma welding in two areas:

- In mass production where highly automated systems outperform manual labor (like repetitive turbine blade and compressor blade tip restoration)
- In highly stressed areas where laser welding can potentially produce weld deposits that offer superior mechanical properties

At Sulzer Elbar, emphasis is placed on the latter.

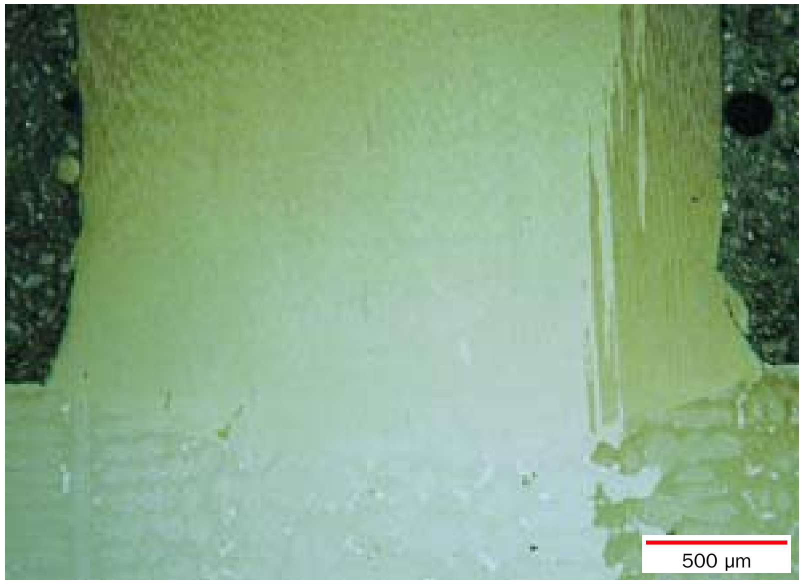
Typical damage that now may be repaired by using laser welding includes:

- Impact damage in the lower part of airfoils
- Cracking in the leading or trailing edges of airfoils
- Cracking in the airfoil surfaces

Usually, the orientation of the defect is random compared to the structure of the DS or SX base material. In these conditions, it is difficult to produce a continuation of the DS or SX structure in the weld deposit.

In equiaxed materials (i.e. conventional cast), the fine grain size of the weld deposit impairs the creep resistance of the weld filler metal. To compensate for this, highly creep-resistant filler metals are selected, modified as necessary, and used (Fig. 1).

Parameters for laser welding can be selected to produce defect-free weld deposits. In conventional inert-gas welding, the use of these highly alloyed weld filler metals would not be possible without producing extensive cracking.



2 This micrograph shows the weldability of high gamma prime DS material (a nickel base casting): The DS structure of the GTD-111 alloy (bottom) is continued in the weld. The filler metal is Inconel 738 LC.

Providing State-of-the-Art Laser Welding

Laser welding with conventional filler metal offers no technical problems and is simply an alternative to normal welding processes. As compared to standard welding processes, it produces less distortion.

In conventional laser welding, the weld deposit material has a fine-grained structure with somewhat reduced high-temperature creep resistance. In DS and SX materials, blade tips and similar simple geometries can be laser-welded using either dissimilar or identical filler materials; the DS or SX structure is continued in the weld deposit.

While the quest for DS and SX laser welding that can be used in random locations on highly stressed heavy industrial gas turbine components is still going on, recent laser welding research has produced highly creep-resistant repair welds in highly creep-resistant rotating blade materials. Base materials that have been welded are Inconel 738 LC and GTD 111 with equiaxed cast structure (Fig. 2). Filler metals that can be used are similar or identical precipitation-strengthened alloys.

The high sensitivity to microcracking during welding in both the base materials and the weld filler metals has been overcome by combined pre- and post-weld heat treatments and a careful design of the welding sequence.

In laser welding, distortion is lower than in conventional welding. Additionally, laser weld beads are narrow and well defined. This makes laser welding particularly suitable for near-net-shape build-up welding: very large, complexly shaped sections can be rebuilt without the need of shaping tools. The achieved high process reproducibility has allowed application in standard production from 2002 on.

The focus of Sulzer Elbar's research and development is now on optimizing the programming of the laser welding equipment to make the process more price-competitive. ◀

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