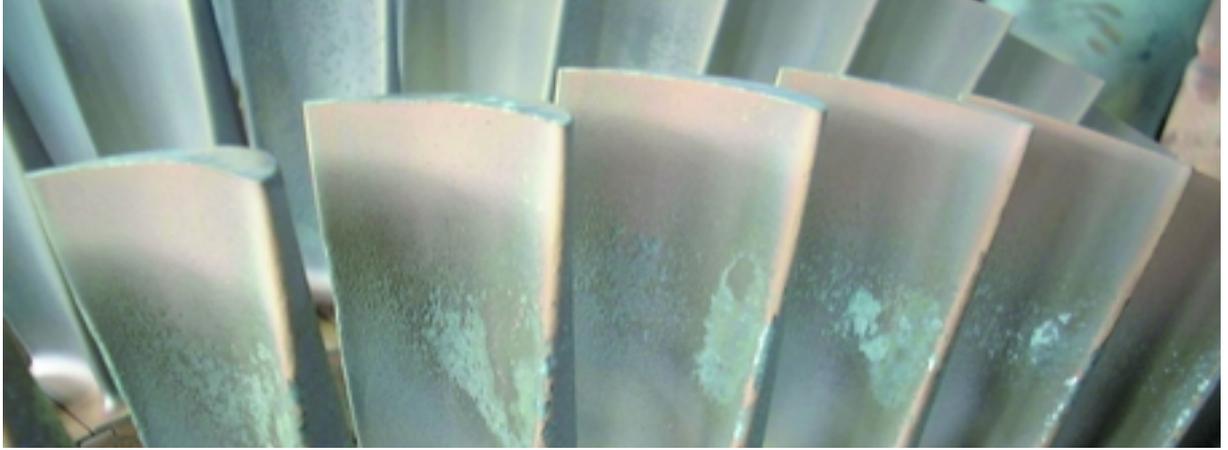


1<sup>■</sup> Repairing worn gas turbine blades (instead of replacing them) helps to save costs.



# An Advanced Repair Technique: Laser Powder Build-up Welding

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*The drive for high-efficiency gas turbines necessitates new materials for the hot-section components, i.e. single-crystal (SX) or directionally solidified (DS) components. Their high intrinsic value and elevated replacement costs call for high-tech repair solutions. To satisfy these demands, Sulzer Elbar (a subsidiary of Sulzer Turbomachinery Services) introduced a novel laser powder welding technology (LPW) in spring 2001. It facilitates not only the rebuilding of substrate material with higher creep-resistant filler alloys, but also the reproduction of the single-crystal structures.*

■ Although modern gas turbines are extremely reliable, wear of the stages – in particular those under severe thermomechanical load – is unavoidable (Fig. 1<sup>■</sup>). Blading repair (instead of replacement) helps to save costs, especially for the latest versions with their directionally solidified or even monocrystalline structure. A new laser powder welding technique gives Sulzer Elbar a broad range of capabilities to expand the repair limits of conventional cast (CC) components and for the repair of future types of gas turbine components.

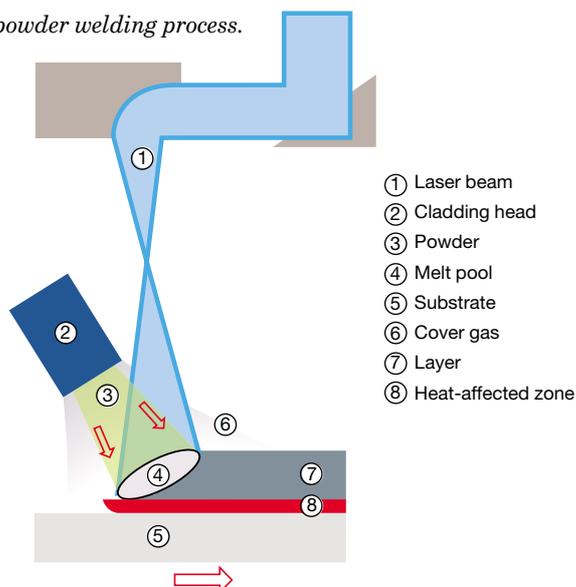
## STANDARD REPAIR PROCESSES

The basic techniques employed by Sulzer Elbar for the restoration of service-degraded turbine components are welding, high-temperature brazing and cladding. Welding is used primarily for the rebuilding of complete wall structures, whereas advanced brazing and cladding technologies are utilized to restore the wall thickness. The repair of advanced gas turbine components with the essence to reproduce the directionally solidified or monocrystalline microstructure requires a combination of dif-

ferent repair techniques and, furthermore, very accurate control of the heat input.

The automated laser welding technology (Fig. 2<sup>■</sup>), which is a combination of the welding and cladding technique, has proven to be the only promising method to fulfil these demands. Thanks to accurately controllable energy input, which permits low heat input and produces small heat-affected zones, limited distortion and good dimensional control of the welding seam, components that had to be scrapped in the past are now rejuvenable.

3<sup>■</sup> Principle of the laser powder welding process.



## THE LASER POWDER WELDING PROCESS

To begin with, the areas that have to be repaired are digitized, and a 3-D model of the component is created. The digitized surface is integrated in the CNC-controlled workstation, which facilitates the compensation of minute changes in the geometry of each part and produces metal deposits of near net shape. A power control program (controlling speed and laser energy depending on the welding parameters) is then correlated with the seam motion, and the build-up welding commences.

The laser beam is guided vertically onto the substrate and focused above the substrate surface.

A weld pool is formed in the area of impingement (Fig. 3<sup>■</sup>). A cover gas stream with entrained powder particles is directed onto the substrate over the area of the laser beam impingement and into the molten pool. Since, in orders of magnitude, the mass of the substrate is thicker than the weld deposit, the sub-

strate acts as a heat sink. Due to the rapid, relative motion between the beam and the melt pool, it cools the melt pool down immediately after formation.

## BUILD-UP OF CONVENTIONAL COMPONENTS

As an example, Figure 4<sup>■</sup> shows the build-up of a rotor blade tip made of precipitation-hardened, CC-superalloy Inconel 738. Figure 5<sup>■</sup> shows the microstructure of the build-up with the dendritic substrate, recrystallized areas in the fusion zone and the build-up layer.

Typical deposition rates can increase to 90 g/min. The layers range in thickness from 0.5 to 1 mm and in widths as small as 0.5 mm and up to 5 mm wide.

The process can be used as a repair technology for CC components. To enable the laser powder welding technology to be used for DS or SX components, the epitaxial (with the same crystal orientation) growth of the microstructure

(columnar dendrites) has to be achieved during the solidification of the melt pool.

The nucleation and growth of equiaxed dendrites, which lead to spurious grains, has to be avoided, because grain boundaries in these directional solidified components decrease the creep strength deleteriously.

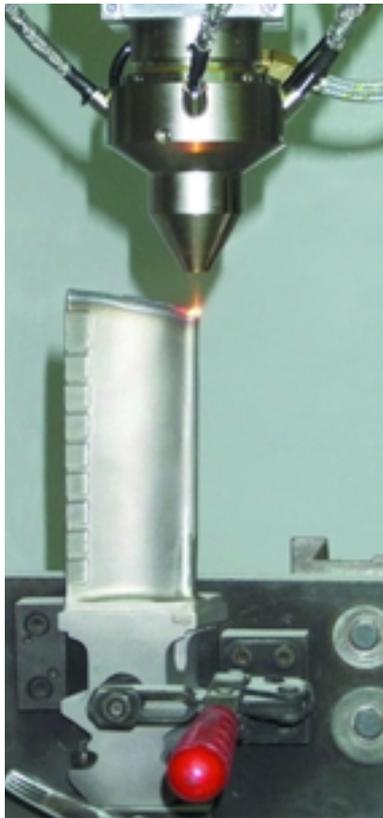
## LPW OF DS AND SX COMPONENTS

Planar front, cellular or dendritic solidification microstructures are formed in the solid/liquid interface during laser power welding. The formation depends on parameters like alloy composition, temperature gradient and the solidification velocity.

The initial solidification on the partly melted substrate is epitaxial. A planar interface is stabilized at high-growth rates. With decreasing growth rates, the cellular structure stabilizes and changes



2<sup>■</sup> The Sulzer Elbar laser center combines a welding and cladding technique for the repair of gas turbine components.



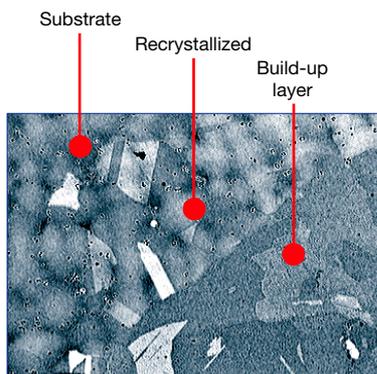
4<sup>■</sup> The tip of a rotor blade being repaired by means of laser welding.

to fine dendrites, which become coarser (Fig. 6<sup>■</sup>).

The desired columnar and epitaxial growth, which can be seen in the fusion zone and the center cone, can only be achieved in a small process window and depends strongly on the component geometry controlling the heat flux. Basic welding parameters have to be attuned to the different component geometries and alloy compositions. If the welding-parameter combinations are found, directionally solidified or single-crystal microstructures can be reproduced. This can be seen in Figure 7<sup>■</sup>, where the microstructure of a DS nickel-base superalloy build-up with a modified MarM002 powder is shown. Moreover, the microstructure shows the applied layers with a thickness of approximately 0.5 mm.

## FURTHER IMPROVEMENTS

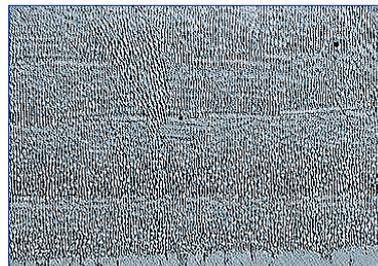
The introduction of this novel technology is part and parcel of a 4-year development program. Up to now, Sulzer Elbar has been in a position to reduce the repair limits and improve the quality and reliability in comparison with standard repair processes. Build-up welding of different types of conventionally cast superalloy components has been performed successfully. With an eye to the future, however, one of the development activities at Sulzer Elbar is focused on the transfer of welding parameters for DS and SX structures for application on gas turbines. This will solve problems associated with heat flux changes due to dimensional changes and microstructural degradation of the substrate during service.  $\Omega$



5<sup>■</sup> Microstructure of Inconel 738 built up with Inconel 738 powder.



6<sup>■</sup> The microstructures change from the center to the flanges, depending on the cooling rate.



7<sup>■</sup> Epitaxial growth on the directionally solidified superalloy MarM002.

## FOR MORE DETAILS

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