Laser Surface Cladding of Titanium Aluminides

Technology and engineering for the turbine blade repair

Thomas Kimme and Mandy Seifert

Laser powder cladding is considered the best available technology for the repair of components from power plant turbines and aviation engine components. With the technical milestone of introducing a new group of materials – the titanium aluminides (in short TiAl) – in the aircraft engine, new requirements of technical / technological challenges need to be meet.

The challenge of a modern world is, amongst others, to develop means of transportation more efficiently and sustainably for transport and logistics. Here, the focus is also on a growing understanding of security and the use of environmentally friendly technologies. In the current Global Aviation Monitor, the Institute of Air Transport and Airport Research forecasts a global growth of five percent in air traffic volume [1].

New materials and production processes are put to industrial use. The material TiAl has been used in the form of cast and forged turbine blades in the aircraft turbine for a few years [2]. Compared with conventionally used materials such as nickel-base alloys, TiAl has a higher degree of hardness, is temperature-resistant and offers weight savings of approximately fifty percent. The resulting fuel savings reduce the emission levels and operating cost of the turbines significantly. Such high value parts are intended to be used again after repairs utilizing a reliable MRO process.

The aim of the research project Reptil was the development of such a repair solution for titanium aluminide blades. The project name stands for the development of an automated repair and production technology using laser surface cladding for engine blades made of titanium aluminides (Fig. 2). The materials TiAl 48-2-2, Ti-4522XD and TNM-V3B were treated. At the end of the research project, the project partners of Fraunhofer ILT, Access, Mabotic, TLS Technik and Laservorm were able to carry out the successful repair of a turbine blade made of TiAl using laser cladding with powder. The technological approach and the mechanical solution components by Laservorm are presented below (Fig. 3).

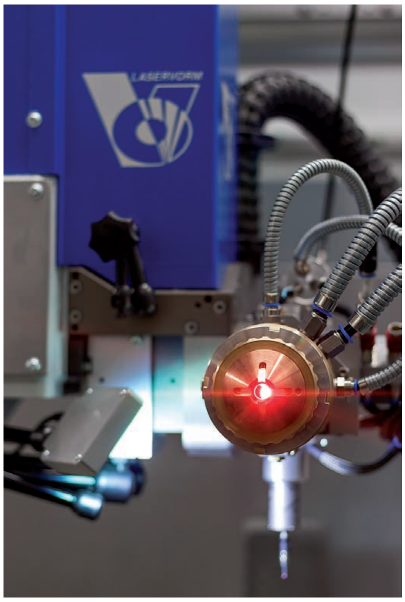

Fig. 1 Geometry acquisition and cladding in a laser system operating adaptively

Approaches pursued

In order to successfully process TiAl, many factors have to be taken into account. The alloy has an affinity to crack. Cracking is caused by tensions which arise from the heat input during cladding processes and the subsequent

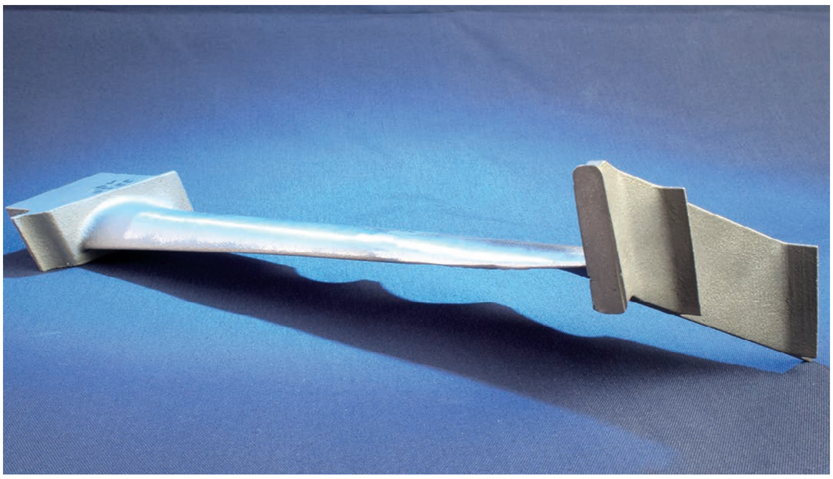

Fig. 2 Demonstrator blade, reworked after cladding by contour grinding

Company

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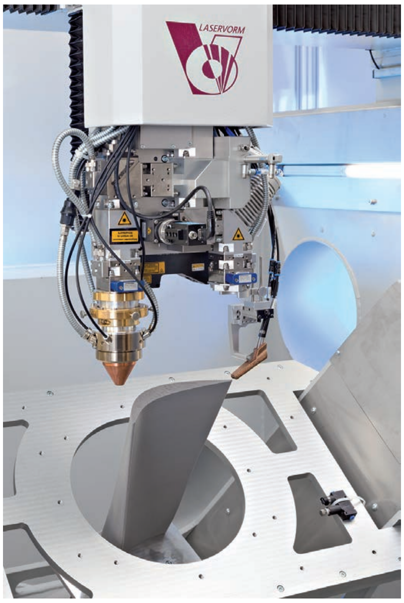

Fig. 3 System for the repair of power plant turbine blades with two optical paths

rapid cooling. Furthermore, the material has strong oxidation tendencies. The affinity of the material for the absorption of the atmospheric oxygen when heating up also leads to an increased formation of cracks due to embrittlement of the alloy. In order to meet this challenge, different strategies were pursued. On the one hand, a defined heat balance with absolute preheating temperatures needs to be set to typical dimensions ranged from 500 to 900 °C in the item. These temperatures have to be guided in a controlled and temporally defined manner during both the heating and cooling of the component after processing. Furthermore, the workpiece needs to be protected by inert gas during processing and heating. The considerable radiated heat of the preheated components has a negative impact on the technology and the sensors. Further frame conditions include the inherently irregular wear and damage patterns – the processing operations very often require real 3D processing and – if the repairs are to be carried out automatically – a 3D geometry acquisition and automatically adapting processing parameters.

Inert gas atmosphere

Preliminary studies of Fraunhofer ILT have shown that an atmosphere with considerably reduced oxygen content is required for processing TiAl. A local inert gas supply (nozzles) was found insufficient to provide argon on the strongly preheated part. As a completely enclosed chamber appears uneconomical for a productive industrial solution, different technical approaches were developed and combined. One developed solution is a modularly constructed inert gas tub, providing the gas flow from various sides and compartments.

The oxygen concentration in the tank is monitored, thus the quality of the inert gas atmosphere can be ensured while assuring optimal gas usage. In case of disturbances (caused e.g. by local hot spots) automatic regulation supplies more inert gas.

The advantage of this solution – which, however, needs to be combined with local protective gas nozzles in many cases – is the accessibility of the processing area by inductor, geometry sensors and powder nozzle. Powder nozzles from the in-house LV Cnozzle series were used.

These nozzles, which feature water cooling up to their tips, can withstand the considerable thermal stress caused by the red-hot processing part and deflected laser light while assuring optimal access to the processing area due to their slim design.

Heat management

Pre- and post heating of the processing area proves to be particularly important for the successful cladding process. Several preheating strategies were pursued for heating the component: Radiant heating, inductive preheating (Fig. 4) and – for very small damaged areas – laser-based local heating using a fast 2-axis beam deflector (scanner).

All types of heating can generate the required preheating temperatures and are thus generally suitable for use in this application. The specific component geometry and damage pattern of each individual case have an influence on the choice of the preheating solution.

In case of the damage scenarios considered during this development project (missing material on the inlet edge of a turbine blade – this may occur e.g. as a so-called cold shut during production of new blades or as damage from bird impact) with an exemplary damage zone / missing volume of 20 mm × 14 mm × 3 mm, inductive preheating proved to be well adequate. The demonstrator part with a maximum expansion of approx. 300 mm was locally preheated.

For significantly smaller components – which would be preheated entirely –, preheating with radiant heating is a plausible thought.

For very small damage patterns, the likes of which may occur e.g. during the new production by casting in the form of pores or cavities (dimensions e.g. 1.5 mm × 1.5 mm × 1 mm), the laser source of the laser cladding system can be used as pre-heating, processing and post-heating source altogether.

For this task, the single-mirror 2-axis piezo scanner LV SpinScan with 2-axis deflection (deflection of the laser beam within the concentric powder nozzle in a diameter of 5 mm on the component surface) embedded into the NC controls of a 5-axis laser cladding machine was operated in combination with laser power modulation to set a local temperature gradient, add material by powder nozzle and subsequently achieve suitable cooldown. Using a high-speed pyrometer allowed the dissolution of scanned and modulated energy input by measuring.

Programmable dimension of the cladding bead

Usually, the finest contour element to be processed determines the width of the (preset to a fixed value) cladding bead. Then, wider component areas to built are created by placing several beads next to each other. Here, the application of the superimposed scan contour and laser power modulation of the LV SpinScan solution provided yet another advantage.

The parameterizing tool Scan Matrix [3] controlledly modulates the

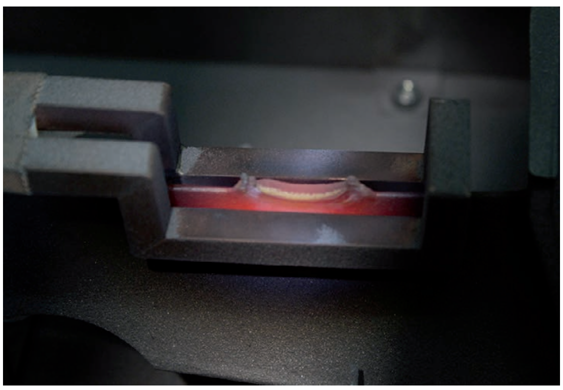

Fig. 4 Repaired zone during the controlled cooling phase

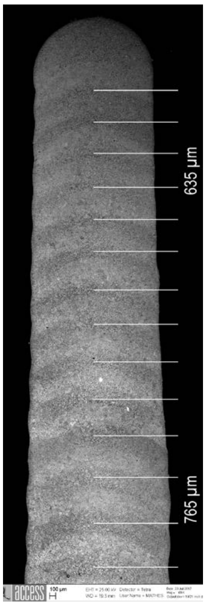

Fig. 5 A repair welding in the metallographic cross-section – the individual layers created with the SpinScan technology are shown (access microsection creation)

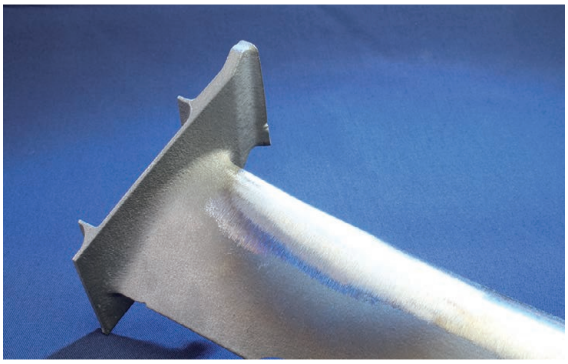

Fig. 6 Demonstrator blade – repaired bird strike damage, grinded

beam and can adjust it to the real machine speed (important during acceleration and deceleration phases of the lead machine) and actual geometry in real time.

Application of this technology and the inherent change in heat input minimizes the risk of cracks in the processed material.

Since this method requires only one processing track per layer, the amount of boundary surfaces between the individual tracks can be reduced (Fig. 5). Potential risks of resulting connection defects or pores which may cause cracks are reduced. Another advantage is that near-net-shape geometries can also be created. Thus, for example, claddings with a triangular profile were created. For this purpose, the scan width of the beam modulation was varied within the individual layers during processing.

Demonstrator

A successfully and automatically executed repair process on a demonstrator part (Fig. 6) proves that the development partners were able to create and engineer a technology that can be both adapted to specific tasks and delivered to the MRO business in a ready-to-use condition. The objective "cold shut repair on demonstrator blade" was led to good processing results (access evaluations) in a demonstrator machine (Laservorm) with integrated laser line scanner for adaptive processing (Mabotic hardware and software), similar powders (TLS) and various processing parameters (Fraunhofer ILT). The results of both the metallography and other studies are positive. In the microsections, there are no signs of cracks and larger pores which would have a negative impact on the resilience of the material. The oxygen concentration in the cladded part areas considered as low and acceptable.

Thus, it is possible to state that the combination of the different technical / technological approaches such as:

- inert gas tub,
- scanning technology,
- inductive preheating,
- temperature control,
- adaptive, automated repair

has been successfully developed.

The Laservorm engineers have transferred the solutions regarding the laser powder cladding of TiAl developed between the project partners and themselves within the framework of the research project into a demonstrator machine and could thus gain knowledge and experience necessary in order to be able to offer complete MRO solutions for this demanding group of materials.

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Authors

Thomas Kimme studied production engineering at Karl-Marx-Stadt / Chemnitz University of Technology. After studying, he was dealing as research assistant with developments regarding the laser powder cladding from 1990 to 1992. From 1992 to 1994, he was working on the research topic "Laser Welding of Ceramics" in the laser center of the Mittweida University of Applied Sciences. In 1994, he initiated the foundation of today's Laservorm GmbH. Since that time, he has been the Managing Director and principal shareholder.

Mandy Seifert has been working as technologist at Laservorm since 2015. After having completed her Bachelor's program of physical engineering with the discipline of measurement and process engineering, she completed the Master's program of nanotechnology at the University of Applied Sciences Zwickau. In her Master's thesis, she examined the topic "Influence of the beam geometry on the result of the laser treatment of hardened surfaces". At Laservorm, her work priorities are the development and implementation of technology as well as quality assurance.

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