FUTURE REGENERATION PROCESSES FOR HIGH PRESSURE TURBINE BLADES

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Abstract

In this paper new technologies for repairing turbine blades are exposed, in which manufacturing processes and materials mechanisms are incorporated. The turbine blades considered here are components of high pressure turbines. This is why the focus of this paper lies on nickel-based alloys. Depending on the size and form of the defects present on the blades, two procedures can be used for repairing turbine blades: cladding and/or high temperature brazing. On one hand a laser cladding process for crack repair was developed, this process can create a single-crystalline solidification of the cladding material. While on the other hand a hybrid repair brazing process was also developed, in which the brazing material and the hot gas corrosion protective coating were applied by means of thermal spraying; an aluminizing of the coating was also integrated into a transient-liquid-phase-bonding-process.

1. INTRODUCTION

For repairing nickel-based turbine blades which are used in the high pressure turbine of a jet engine, two procedures are used depending on size and form of the defects [1, 2]: laser cladding and/or high temperature brazing. Regarding the repair brazing of turbine blades the following steps are carried out [3]: the coating has to be removed from the damaged turbine blade to reveal the nickel-based substrate material. The decoated turbine blade is usually cleaned by means of fluoride ion cleaning (FIC). After inspection and expertise of the present defects the brazing material is applied on the region to be repaired. Typical ways are manually pasting using a dosage pin, a brush or a spattle. Tapes, melt-spin foils or brazing material moulded parts can be used to apply the brazing material as well. The brazing process is carried out in a high vacuum furnace with a pressure less than 10^{-5} mbar. The brazing material wets the substrate material and due to the capillary activity fills the gap to be brazed. After the brazing process the components are near net shape machined which is time-consuming and expensive. The cooling holes are reintroduced by means of drilling or via a laser process. To protect the turbine blade against hot-gas corrosion a MCrAlY-coating (M = Ni and/or Co) is applied especially by vacuum plasmaspraying (VPS) or electron beam physical vapour deposition (EB-PVD). But also high velocity oxygen fuel spraying (HVOF) and atmospheric plasmaspraying (APS) are more and more employed because these technologies are constantly developed further regarding to low oxide coatings. To increase the oxidation resistance of thermally sprayed coatings (especially APS) the MCrAlY-coating is aluminized additionally and is carried out by means of chemical vapour deposition (CVD).

Regarding to the brazing process the laser repair process starts with the equal preparation steps. To reduce the contamination during the material deposition process, the coating has to be removed as well as in the brazing process. The laser repair itself is divided into six steps – First, the removal of the damaged area. Second, the test for possible cracks and as a third step the removal of these cracked areas by milling. The fourth step is the man-made repair of the cracked area and the fifth step is the laser cladding process to renew the tip area. After the repair of the tip, the original shape of the blade has to be reintroduced as the sixth step of the laser process. This procedure is, at the moment, not applicable for other regions than the tip-area of the high pressure blades. Also, this cladding process results in a polycrystalline solidification of the material – this reduces the strength of the material and the service life as well. Through the use of two different alloys which cause diffusion processes, a second repair is not allowed. After machining the blade, the application of the protection layer is also needed in further steps like in the high temperature brazing process.

The above mentioned processes for repairing turbine blades are the state of the art and in this paper new technologies for repairing turbine blades are introduced.

In earlier works [5, 7] the development of a two staged hybridtechnology to reduce the process chain of repair brazing turbine blades is described (figure 1).
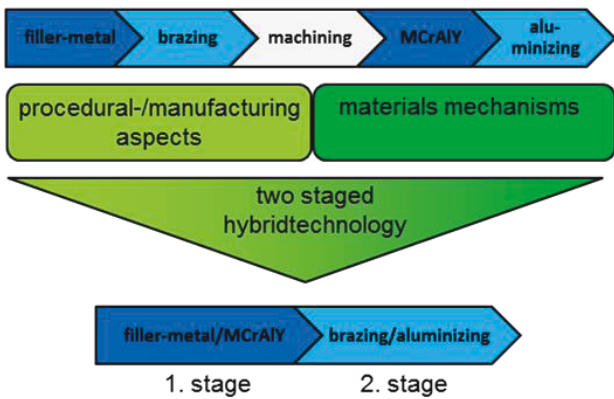
FIGURE 1.   Process chain (present and future) for repair brazing turbine blades

In this technology the brazing material and the hot gas corrosion protective coating are applied in a mutual process by means of thermal spraying which is the first stage of this hybridtechnology. The second stage of this process integrates the brazing section (transient-liquid-phase-bonding-process) into the CVD aluminizing. The principle of this hybridtechnology is shown in figure 2.
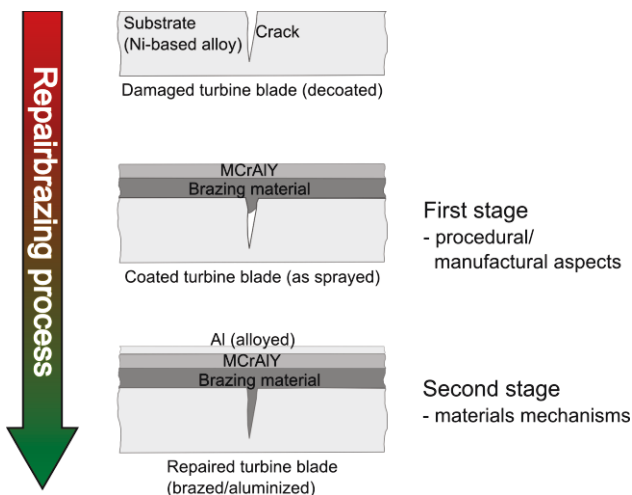

FIGURE 2.   Principle of repair brazing/aluminizing turbine blades

At the same time [6] it was possible to develop a laser repair process which can create a single-crystalline solidification of the cladding material. In both processes, brazing and cladding, it is necessary to remove the coating of the damaged turbine blade completely. Due to possible residues a contamination can lead to unsatisfactory results of the turbine blade regeneration. The residues lead to a change of the alloying components and can cause an unwanted nucleation in the single crystal cladding process. In case of the brazing process the contaminations result in a bad wettability and joining of the brazing material to the substrate. Both processes consider two different kinds of defects. The hybrid brazing process is laid out to regenerate small cracks (up to 1,000 µm depth and 20 µm width) and near-surface defects of the turbine blade. The laser cladding treatment is specially designed for regenerating large defects like incomplete turbine blades and cracks. In this work results

of the developed technologies are presented.

2.   EXPERIMENTAL

2.1.   Hybrid repair brazing process

The experimental procedure is described in [7]. Inconel 718 flat specimens were used. The probes were corundum blasted (high grade alumina EKF 20), cleaned in an ultrasonic bath and coated subsequently. The coating of the nickel-based alloys (brazing material Ni650 and MCrAlY) was carried out by means of APS (F4 torch, Oerlikon Metco) and HVOF (K2 torch, GTV). The compositions of the used materials are shown in table 1.

Material	Ni	Co	Cr	Si	Al	Y
Ni650	71		19	10		
NiCoCrAlY	47.5	23	17		12	0.5

TAB 1.   Compositions (in wt.%) of used materials for repair brazing

The brazing temperature of the brazing material is 1,190 °C. The spraying parameters are the same for the brazing material and the hot gas corrosion protective material (table 2).

	APS	HVOF
Ar /L·min^{-1}	55	-
H$_2$ /L·min^{-1}	9.5	-
J /A	600	-
Kerosene /L·h^{-1}	-	24
O$_2$ /L·min^{-1}	-	800
Nozzle distance /mm	120	300

TAB 1.   Spraying parameters

For the aluminizing process a powder package is used containing 3 wt.% aluminium fluoride (AlF$_3$), 1 wt.% Aluminium (Al) and 96 wt.% Alumina (Al$_2$O$_3$). The principle of the aluminizing is shown in figure 3. The specimens were embedded into the powder package and the combined brazing/aluminizing process was carried out in a high vacuum furnace. To evaluate the coatings and the results of the brazing/aluminizing process metallographic cross-sections and optical-microscopic pictures were prepared.
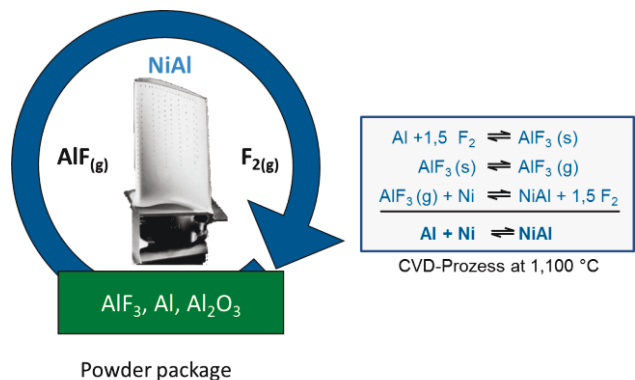

FIGURE 3.   Principle of aluminizing

2.2.   Laser repair process

The experimental procedure for the single crystal cladding process is described in [6] and [8]. For test

specimens, as well as for the powder material the nickel base-alloy CMSX-4 was used. The probes were cleaned before the test and the cladding was carried out by a diode laser (Laserline LDF650). The composition of the used material is shown in table 2.

Material	Ni	Co	Cr	Ta	W	Al
CMSX-4	61,7	9,0	6,5	6,5	6,0	5,6
Material	Re	Ti	Mo	Hf		
CMSX-4	3,0	1,0	0,6	0,1		

TAB 2. Composition (in wt.%) of CMSX-4

The melt temperature for the used material is about 1,350 – 1,360 °C. The grain size of the powder is 45 ± 25 µm. The parameter for cladding volumes and cracks on the tip as well as the parameter for the repair of cracks along the trailing and leading edge are shown in table 3.

	Cladding volumes	Crack cladding	Crack T/L cladding
T Control / °C	1,400	1,400	-
Power Laser / W	100 – 350	75 – 350	300
Powder / g/min	3	2	1
Feed / mm/min	100	100	200

TAB 3. Cladding parameters

For all tests, flat substrates were used. First cladding tests were done on the edges of these flat surfaces, to evaluate the single crystal growth of material on the tip of a blade. Second tests were done on a notched flat surface, which represents the removed cracked region area on a tip. The third parameter setup was done to evaluate the repair of small cracks at the leading and trailing edge of a blade. These assumptions are chosen through analysis of different damaged parts. To evaluate the cladding process and the orientation of the microstructure on metallographic cross-sections, optical-microscopy pictures and electron-backscattering-diffraction (EBSD) pictures were prepared.
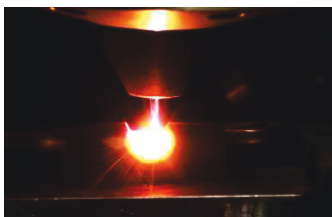

FIGURE 4. Principle of single crystal crack cladding

3. RESULTS AND DISCUSSION

3.1. Hybrid repair brazing process

In previous works [7, 9] could be shown that it is possible to apply the brazing material and the hot gas corrosion protective coating in a common process by means of thermal spraying. The applied brazing material shows a good crack infiltration capacity. But the longer the brazing material is in the liquid state the more cavities or pores in the brazing material are formed (figure 5).
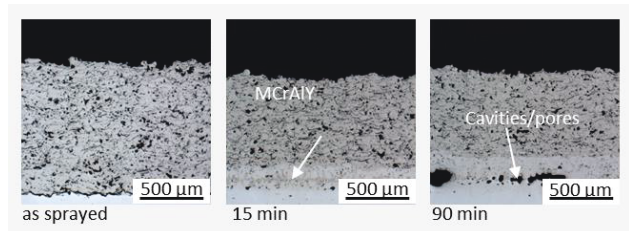

FIGURE 5. Common coating and heat treatment of brazing material/MCrAlY (APS)

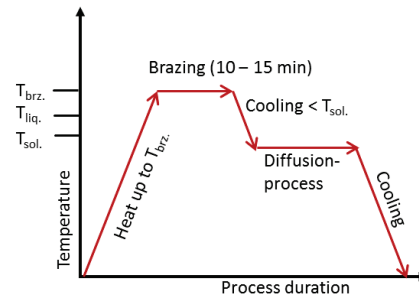To that effect the temperature-time regime is adjusted to minimize the pores (figure 6).

FIGURE 6. Temperature-time regime of the brazing/aluminizing process to reduce pores or cavities

The prepared specimens were heated up in the aluminizing powder package to the brazing temperature and the brazing section lasts 10 to 15 minutes. The temperature then was lowered just under the solidus of the brazing material. At this point the partial pressure of the aluminium is still high enough to alloy with the MCrAlY coating. Figure 7 depicts the result of the brazing/aluminizing process. Compared to the heat treatment of the coating system shown in figure 5 the pores in the brazing material were reduced. The cross-section on the left in figure 7, shows the brazing/aluminizing process with a total duration of 735 minutes (15 minutes brazing time at brazing temperature and 12 hours below solidus of the brazing material) and only some pores can be observed. On the right side two huge pores can be found although the process duration was just 135 minutes (15 minutes brazing, 120 minutes below solidus). In all mentioned processes one can also find the nickel-rich phases (bright regions) and brittle phases (dark regions) in the brazing material.
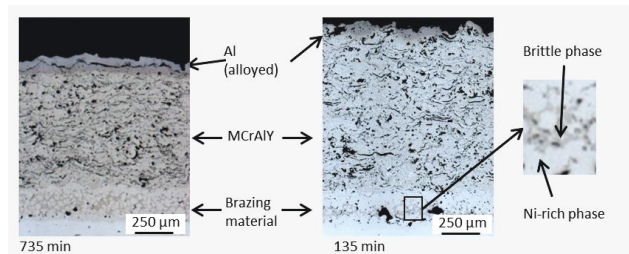

FIGURE 7. Brazing/aluminizing process

The reason that pores still occur could be small local differences in the composition of the brazing material which can lead to early fused spots. To equalize or

minimize these composition differences the previous temperature-time regime is enhanced by a homogenisation annealing step (figure 8).
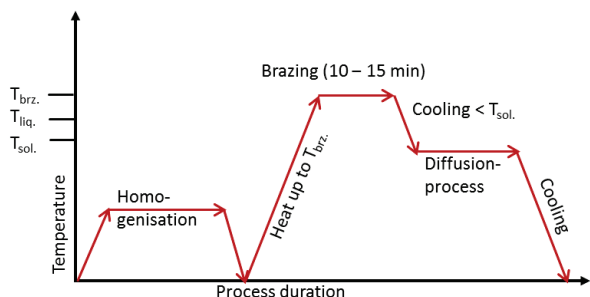

FIGURE 8.   Enhanced temperature-time-regime

Figure 9 shows the cross-section of the coating. The duration of the homogenisation was 24 hours. The following brazing/aluminizing process lasts 735 minutes so that the heat-treatment had a totally duration of 36.25 hours.
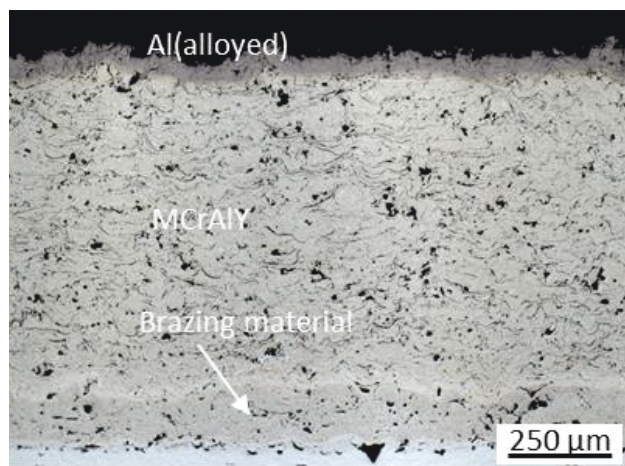

FIGURE 9.   Brazing/aluminizing process with homogenisation step

The results show that a formation of pores is unavoidable however the pores are evenly distributed compared to the result shown in figure 6. Another effect which can be seen is that the brittle phases are minimized as well.

As mentioned in section 2 (Experimental) the HVOF process was taken into account and the results are essentially the same. Figure 10 summarizes the results of the HVOF coating system. Figure 10a shows the state as sprayed. Figure 10b depicts the heat-treatment of the coating after a brazing time of 90 minutes at brazing temperature, pores are formed in the brazing material. In figure 10c the coating was heat treated as shown in figure 6 (brazing and diffusion process). The brazing time was 15 minutes and the diffusion process below solidus had a duration of 2 hours, locally pores can be observed. The enhanced heat-treatment due to figure 8 of the coating is shown in figure 10d. The homogenisation time was 24 hours, brazing time 15 minutes and the diffusion process 12 hours. The pores and the brittle-phases in the
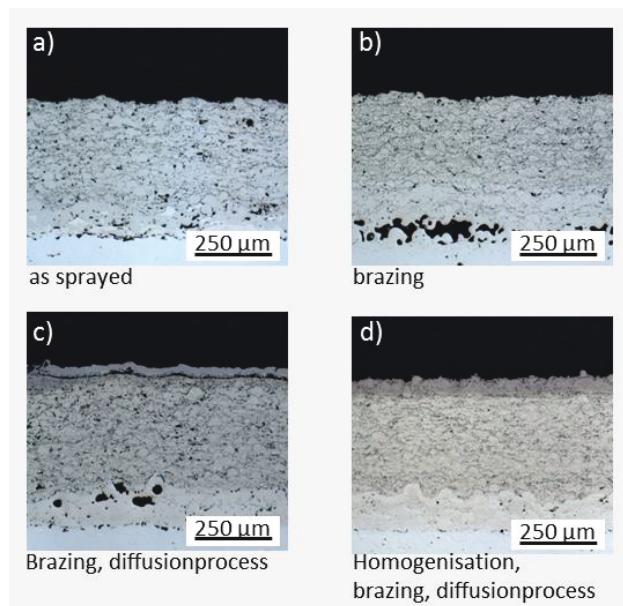
brazed seam are minimized.

FIGURE 10.   Brazing material/MCrAlY coating by means of HVOF

3.2.   Laser repair process

In previous works [6] the application of single crystal volumes on flat substrates was shown. For the repair of these components it is important, that the surface is perfectly cleaned before the laser process. The presence of an oxide-layer at the surface led to the formation of grains inside the cladded volume. To prevent its diffusion into the processed area a removal of these oxide-layers, on the work zone and in a small area around, was executed. Consequently the clad did not presented more stray grains (figure 11).

FIGURE 11.   Cladded volume on a flat substrate

It was also shown [8], that the preheating of the surface is in most cases not needed. However for the cladding of a large area, the use of a preheating is needed to prevent the volume from cracks. By the use of an inductive preheating during the test, the formation of cracks was reduced. But on the other side, the use of a preheating source reduced the single crystal morphology. In sequences for the evaluation of the preheating influence and the cladding, several tests were carried out. The balance between crack-protection and non-single-crystal-morphology had to be found. The combination of a well formed preheated area and a combined cladding process can form the repair clads. With the found parameter setup, a combination of crack repair- cladding and volume build was performed. To simulate a cracked

turbine blade, a substrate was notched by use of a milling machine to produce a geometry, which could be cladded in the following steps. First the preparation of the substrate, followed by the preheating and the crack repair process filling the notch. In the next step, to avoid solidification and pollution of oxides in the process, the surface was cleaned again. On the flat surface, the material was built up to simulate the repair of the tip of a turbine blade (figure 12).

FIGURE 12.   Crack and volume cladding

In most of the cladded parts, cracks could be found. Just the optimum combination of preheating and cladding could reduce the crack formation.

Figure 13 shows the cladding on the leading or trailing edge as deposited at the area of the flat substrate. By use of only a small amount of powder during the process, just to fill small gaps, the material is repaired.
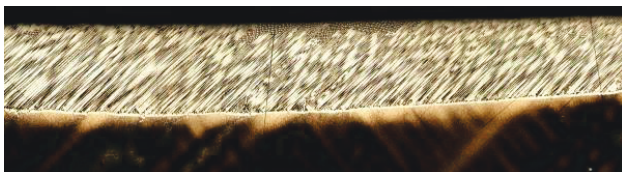

FIGURE 13.   Cladded volume on the "leading edge" area

Most of the energy was used to remelt the surface and reproduce the structure of the microstructure. To validate the orientation of the cladded area, an EBSD-analyse was carried out to show possible misorientations inside the clad. In figure 14 a small area with measured orientations is shown.

FIGURE 14.   EBSD analysis of the cladded structure in figure 14

Most of the measured area presented a well orientated area. In the middle of the EBSD-picture some pixels show a possible misorientation inside the orientated dendrites.

4.   CONCLUSION

In this paper new repair strategies for the regeneration of turbine blades are presented. Concerning the repair brazing the feasibility of a two staged hybridtechnology was shown. It is possible to apply the brazing material and the hot gas corrosion protective coating in a common step by means of thermal spraying which is the first stage of the hybridtechnology. In this study it was shown that the combination of brazing and aluminizing – representing the second stage – is possible as well. The

aim for the future is to strengthen the brazed seam by means of a γ' (Ni_3Al) precipitation hardening to increase the number of repair cycles for the turbine blade regeneration, with this objective the microstructure must be rebuild. The use of a microstructure similar to the original shape, reduce the crack formation in further operations and lead to a new-like material behaviour of the repaired material. Even the use of the same material itself increases the lifetime. The repair methods described also improve the existent repair methods or even optimize substantially the whole repair technology for these expensive parts. The repair of local defects and the deposition of similar material with equal properties mark up the technologies of tomorrow.

5.   ACKNOWLEDGEMENT

6.   REFERENCES

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