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Regeneration of high pressure turbine blades. Development of a hybrid brazing and aluminizing process by means of thermal spraying

M. Nicolaus[a*], K. Möhwald[a], H. J. Maier[a]

[a]Leibniz University Hannover, Institute of Materials Science, An der Universität 2, 30823 Garbsen, Germany

* Corresponding author. Tel.: +49 2302 661 647; fax: +49 2302 661 650. *E-mail address:* nicolaus@iw.uni-hannover.de

Abstract

Besides welding, high temperature vacuum repair-brazing is already established for nickel-based alloy turbine blades in the aerospace and power plant industries. After the worn turbine blade has been decoated to its substrate material, the filler metal is deposited as a paste, (melt-spin) foil or tape which also consists of a nickel-based alloy. Following this, the hot-gas corrosion protective coating (e.g. NiCoCrAlY) is applied using thermal spraying. The brazed turbine blade is ground or milled to size and subsequently aluminized to further increase its corrosion resistance. Using the current state of technology, a turbine blade can undergo approximately 3 to 4 repair cycles. In the present study, the development of a two-stage hybrid technology for repairing turbine blades is considered which incorporates, on the one hand, a process technology and manufacturing aspects and, on the other hand, considers material-technological mechanisms. During the first stage of this hybrid technology, the filler metal together with the hot-gas corrosion protective coating is applied using thermal spraying. The subsequent second stage combines the brazing and aluminizing processes. The technology developed here brings technical and economic advantages whilst enabling the current state-of-the-art's corresponding process chain for repairing turbine blades to be shortened.

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Keywords: thermal spraying, repair-brazing, aluminizing

1. Introduction

The repair of nickel-based alloy turbine blades, such as those employed in the high-pressure turbines of aircraft, are essentially carried out in two processes which depend on the size and type of defect [1, 2]: laser cladding and high-temperature brazing. Repair brazing, which is the focal point of the current study, generally consists of the following processing steps [3]: Firstly, the defective turbine blade is decoated to its substrate material and subsequently cleaned using Fluoride Ion Cleaning (FIC). After the subsequent inspection and assessment of the defects, the filler metal which also consists of a nickel-based alloy, is manually applied as a paste using a spatula or dispensing needle. Tapes and (melt-spin) foils as well as moulded parts of braze material are employed as well. Owing to the materials used, the brazing process is carried out at high-vacuum ($p < 10^{-5}$ mbar). The filler metal wets the component and, due to capillary action, the existing defects, such as cracks, are filled and a material integrated bond is produced. Following this, time-consuming and expensive post-grinding is carried out to restore the brazed turbine blade to its near-net-shape. The cooling holes are redrilled using (laser) drills. In order to protect the turbine blade against hot-gas corrosion, an MCrAlY coating (M = Nickel and/or Cobalt) is applied using either vacuum-plasma-spraying (VPS) or electron-beam physical vapour deposition (EB-PVD). In addition to this, high-velocity oxy-fuel (HVOF) and atmospheric plasma spraying (APS) are increasingly employed since the technical equipment is being continuously developed with regard to low oxide coatings. To increase the oxidation resistance of thermally sprayed coatings (particularly APS), additional

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aluminizing of the MCrAlY coating is carried out. Independent of the spraying process, a diffusion heat treatment of the MCrAlY coating takes place in all cases. In addition to this, pure aluminizing- or PtAl-coating (without MCrAlY) are carried out. Aluminizing is usually produced using chemical vapour deposition (CVD), the PtAl coating is generated by means of the following process steps; Pt metallizing, diffusion heat-treatment and aluminizing. The repair process depicted here reflects the current state-of-the-art. In this contribution, the development of a two-stage hybrid technology is introduced for repairing turbine blades.

The material structure of a turbine blade is nickel-based from the substrate material and filler metal to the hot-gas corrosion protective coating. The alloys are metallurgically compatible and can, to a large extent, be easily matched to each other. This is particularly the case for the filler metal alloy's system (Ni-(Co)-Cr-(B)-Si) and the hot-gas corrosion protection system (Ni-Co-Cr-Al-Y). In addition to this, both systems are powder metallurgically processed which, in turn, implies simultaneous processing by means of thermal spraying. Besides applying the hot-gas corrosion protective coating, the application of the filler metal using thermal spraying was also verified by Bach et al. [4, 5] as a standard technology. Thus the simultaneous application of the filler metal and the hot-gas corrosion protective coating using an integrated technology appears consistent and therefore constitutes the first stage of the hybrid technology. In the second stage, the brazing and aluminizing processes are integrated. In earlier studies [6, 7], it could be shown that by using this technology it is, in principle, possible to shorten the process chain, corresponding to the current state-of-the-art, for repairing turbine blades (figure 1).

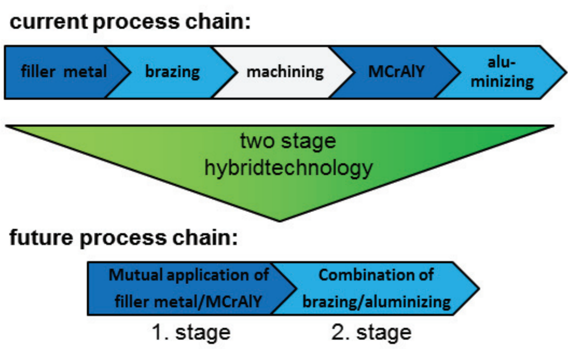

Fig. 1. Process chain (present and future) for repair brazing turbine blades

Figure 2 depicts the principle of the hybrid technology introduced in this study.

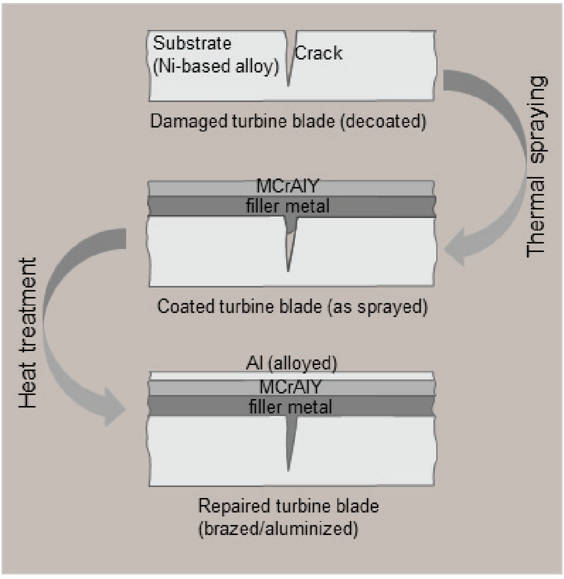

Fig. 2. Principle of the two-stage hybrid process

With the development of this two-stage hybridtechnology it is possible to reduce the current process chain for repairing turbine blades which has technological and economic advantages. This technology fits well in the concept of Through-life engineering Services (TES) providing product support.

2. Experimental method

The details of experimental work are described in [7]. Flat specimens of Inconel 718 were employed. The specimens were blasted with fused alumina EKF 54 and the residual blasting particles were removed in an ultrasonic bath. The coating (filler metal Ni650 + MCrAlY) was applied by means of atmospheric plasma spraying (APS, F4 torch, Oerlikon Metco) or by high-velocity oxy-fuel (HVOF, K2 torch, GTV Verschleißschutz). The chemical composition of the materials employed is shown in Table 1.

Table 1. Composition (in wt. %) of the material used for repair brazing

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

The brazing was carried out in a high vacuum furnace at 10^{-5} mbar and at a temperature of 1,190 °C. The spraying parameters for the filler metal and the MCrAlY alloy are identical and are listed in table 2.

Table 2. Spraying parameters

	APS	HVOF
Ar /L·min^{-1}	55	-
H_2 /L·min^{-1}	9.5	-

J /A	600	-
Kerosene /L·h–1	-	24
O2 /L·min–1	-	800
Nozzle distance /mm	120	300

A Powder package was employed for the aluminizing process. The powder consisted of 3wt.% aluminium fluoride (AlF_3), 1wt.% aluminium (Al) and 96wt.% alumina (Al_2O_3). The principle of aluminizing, which involves a chemical transport reaction, is depicted in figure 3. The coated Inconel 718 specimens were embedded in the powder package, and the combined brazing and aluminizing processes is carried out in a high vacuum furnace. To assess the thermally sprayed coating and the results of the brazing and aluminizing processes, metallographically prepared samples and light microscopy images were recorded.

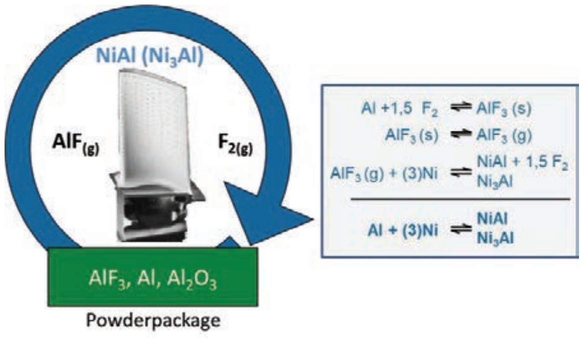

Fig. 3. Aluminizing process

3. Results and discussion

In earlier studies, it could be shown [8, 9] that it is possible to apply the filler metal together with the hot-gas corrosion protective coating using a single thermal spraying process. The thermally sprayed filler metal exhibits sufficient crack-penetrating capabilities and demonstrates material integrated bonding to the substrate (figure 4).

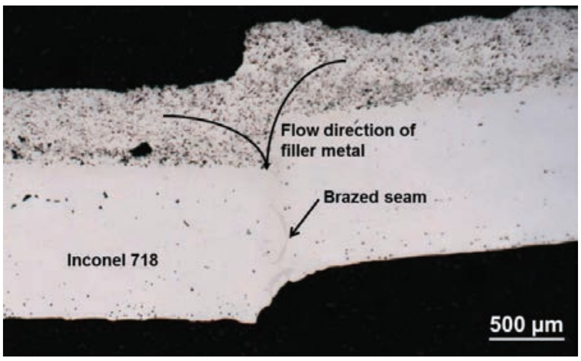

Fig. 4. Crack penetration of APS sprayed filler metal

In this case, a simple brazing process (heat treatment) was carried out. The specimen was heated to the brazing temperature at a heating rate of 20 K/min. The holding time at this temperature was 15 min. However, the duration of the brazing time is too short to adequately carry out the aluminizing. In further tests, the brazing time was accordingly extended. However, it was shown that on increasing the heat-treatment time, in which the filler metal is molten, the fraction of pores in the filler metal increases (figure 5). This can be mainly attributed to diffusion processes and segregation effects. According to the porosity of the MCrAlY coating, the penetration of the molten braze into the MCrAlY coating also contributes to the formation of pores.

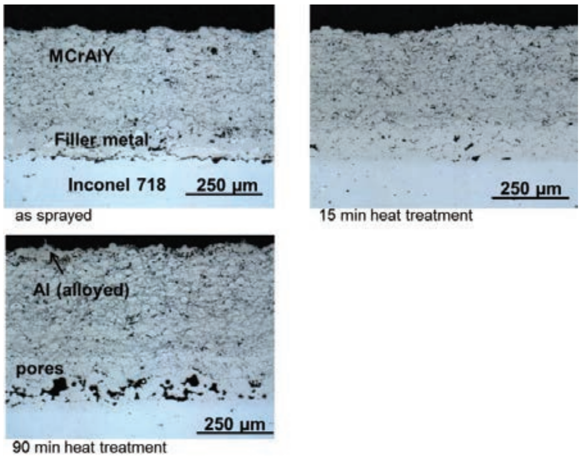

Fig. 5. Integrated coating (HVOF) and brazing/aluminizing of filler metal/MCrAlY

To minimise pore formation, the heating process was modified such that the specimens were heated to the brazing temperature and held at this temperature for 10 – 15 min. Following this, the specimens were cooled to just below the filler metal´s melting point (1,000 °C) and held at this temperature for two hours (figure 6).

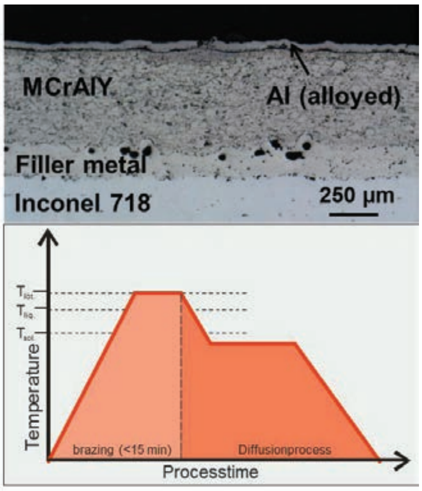

Fig. 6. Enhanced temperature-time-profile for brazing/aluminizing

At this temperature, the aluminium's partial pressure is still sufficiently high for it to be able to alloy with the MCrAlY coating. The result of this heat treatment is also depicted in figure 6. Although it was possible to lower the fraction of pores in comparison with that of the heat treated specimens in figure 5, pore formation was still not completely suppressed. A possible reason for this could be local differences in compositional concentrations in the filler metal which contributes to an additional lowering of the melting point at these locations. In order to compensate for these differences in concentrations, a homogenisation heat-treatment is carried out prior to the enhanced temperature-time profile depicted in figure 6 (see figure 7). The result of this heat treatment is also depicted in the micrographs in figure 7. The duration of the homogenisation heat-treatment was 24 hours at 700 °C. The subsequent brazing and aluminizing processes took 735 minutes, thus the entire heat-treatment process lasted a total of 36.25 hours.

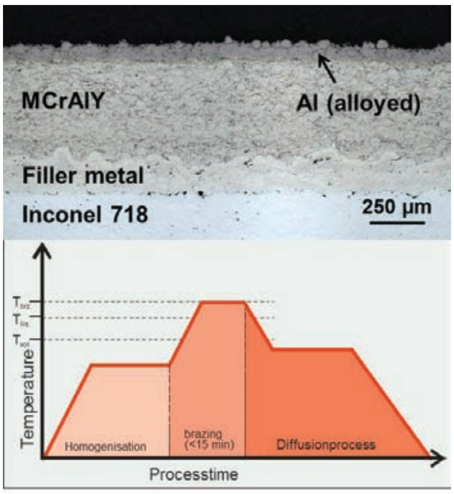

Fig. 7. Enhanced temperature-time-profile for brazing/aluminizing including homogenisation

The results show that the fraction of pores in the braze material can be almost completely reduced using this type of heat treatment.

As mentioned in the previous section 2 (Experimental method), atmospheric plasma spraying (APS) was also considered and essentially demonstrated the same results. These are summarised in figure 8. Figure 8a shows the state directly after coating. Figure 8b depicts the heat treatment of the coated substrate for a brazing time of 90 minutes during which pores also form in the braze. The sample depicted in figure 8c has undergone a heat treatment corresponding to that shown in figure 6. The enhanced heat-treatment process including the homogenisation is shown in figure 8d.

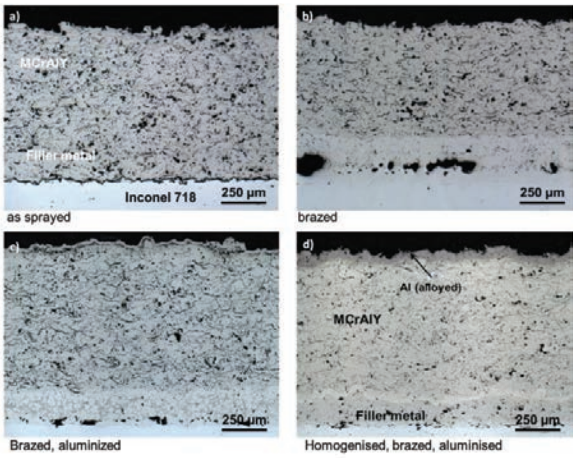

Fig. 8. Filler-metal/MCrAlY coating by means of APS

4. Conclusion

Through-life Engineering Services (TES) provide product support and the two stage-hybrid technology described in this work fits well in this concept. In this research work, it was possible to optimise a two-stage hybrid technology, as already described in earlier studies, to shorten the process chain for repairing turbine blades. The first stage of this hybrid technology constitutes simultaneously applying the filler metal (Ni650) and the hot-gas corrosion protective coating (NiCoCrAlY), whilst the second stage constitutes a combination of the brazing and aluminizing processes. However due to diffusion, penetration and segregation processes, pores form in the filler metal with increasing heat-treatment duration. Based on these results, the temperature control was optimised such that it was possible to minimise and to even almost completely suppress the formation of pores. This optimised temperature control consists of homogenising (to possibly compensate for locally occurring differences in compositional concentrations), brazing and diffusion heat treatments. Future research work should modify the temperature control such that a γ‘-Phase (Ni_3Al) precipitation hardening is obtained in order to elevate the creep strength of the brazing seam.

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