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Additive manufacturing for the repair of gas turbine blades with internal cooling channels: A sealing approach to prevent powder penetration

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Abstract

Gas turbine blades require regular maintenance due to severe corrosion caused by high operating temperatures. After reaching the end of their life cycle, these components need to be replaced. However, repair of such components can contribute significantly to both sustainability and cost-efficiency [1]. Additive manufacturing (AM) offers a promising solution for customized repair of turbine blades due to its design flexibility. In this approach, the damaged section of the blade is removed and the missing geometry is rebuilt additively. One major challenge in repairing turbine blades using Laser Powder Bed Fusion (LPBF) arises from the presence of internal cooling Channels. When the damaged section is cut off, these cavities become exposed, allowing metal powder from the build chamber to fill them during the printing process. This can compromise the functionality of the cooling channels. To address this issue, a sealing concept was developed in this study that prevents the penetration of metal particles into the cavities during the LPBF process. This sealing system can be removed after the printing process is complete, ensuring the integrity of the internal cooling structures.

Laser Powder Bed Fusion, Gas Turbine Blade Repair, Sealing Technique

1 Introduction

The gas turbine blades are subjected to significant thermal stresses due to the high operating temperatures. These stresses often lead to the formation of macroscopic cracks, particularly at the blade tips [2]. To restore the damaged areas, the affected regions are first removed and subsequently reconstructed using Laser Powder Bed Fusion (LPBF). This additive manufacturing process not only enables the restoration of the blade geometry but also allows for the subsequent optimization of the cooling air cavities within the blade structure [3]. A critical challenge during the restoration process is the inadvertent infiltration of powder particles into the cooling channels during the LPBF procedure, which can adversely affect the blade's cooling efficiency.

This study proposes and investigates a new sealing technique designed to temporarily block the cooling channels of turbine blades during LPBF-based repair. The method aims to prevent powder contamination while allowing for complete post-process removal of the sealing material. This ensures the restored component maintains its functional integrity and is safe for reuse. The work contributes to the advancement of hybrid manufacturing strategies by improving the reliability and sustainability of repair processes for high-performance aerospace and energy components.

2 Methodology

The repair of cast turbine blades via LPBF process necessitates high processing temperatures, typically reaching up to $\Theta = 800$ °C, due to the use of nickel-based alloy powders. This thermal environment mandates that any temporary sealing material employed to protect internal cooling channels maintains both dimensional integrity and structural cohesion at these elevated temperatures throughout the LPBF process. Furthermore, the sealing material must be completely removable post-LPBF, leaving no residual obstruction within the channels.

To address these requirements, a custom-developed composite sealing material was investigated. This material consists of a thermosetting resin matrix (H26C) combined with aluminum hydroxide ($Al(OH)_3$) as a filler. The resulting paste exhibits a malleable consistency, which facilitates precise application and effective sealing of intricate internal geometries.

The thermal stability of this composite was rigorously evaluated through furnace exposure at $\Theta_1 = 800$ °C. Although superficial cracks were observed on the material surface post-treatment, these did not compromise the internal integrity or sealing performance of the material within the protective cavities.

Removal of the solidified sealing material was achieved chemically via the internal cooling channels, which represented the sole accessible extraction pathway. An aqueous ammonia solution with a concentration of $c_a = 25$ % and pH > 13 was utilized for this dissolution process.

To validate the sealing concept under realistic repair conditions, the composite was applied to a turbine blade featuring internal cooling cavities with widths of b < 20 mm and to four additional blades with narrower boreholes with diameters of d < 3 mm. Subsequently, the sealing material was thermally cured at $\Theta_2 = 300$ °C for the duration of t = 60 min to ensure complete polymerization. Following the curing step, the damaged blade tip regions were successfully rebuilt using the LPBF process, thereby completing the repair cycle.

3 Results

To evaluate the potential effects of ammonia on the turbine blade material and to verify the complete removal of sealing residues at the interface between the base material and the additively manufactured tip, metallographic cross-sections were prepared from repaired components and analyzed using scanning electron microscopy (SEM). In the SEM micrographs, shown in Figure 1, a surface oxide layer on the cast material was visible as a dark gray region. Bright or white areas within the cast substrate were identified as carbides, which are typical features of cast alloys. In the bonding zone between the cast base and AM-fabricated crown, carbides were occasionally observed extending into the additively manufactured region. No material degradation or anomalies were detected at the cast edge, within the LPBF region, or across the transition zone. These observations indicate that the use of ammonia under the examined conditions does not adversely affect the blade material.

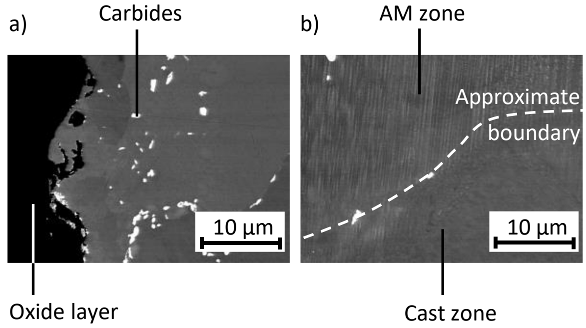

Figure 1. SEM images of cross-sections from an additively repaired turbine blade: a) cast zone; b) bonding zone between the cast base and the additively manufactured region.

To further investigate possible chemical alterations induced by the ammonia solution, energy-dispersive X-ray spectroscopy (EDS) was performed on selected cross-sections. Elemental composition was measured at distances of $a_1 = 10$ µm, $a_2 = 100$ µm, $a_3 = 500$ µm, $a_4 = 700$ µm and $a_5 = 1{,}000$ µm from the external surface, in both the cast and AM regions. The results, presented in Figure 2, showed fluctuations in the measured values of $\Delta w = 8$ %. These variations are attributed to methodological uncertainties, particularly considering the penetration depth of the technique, which can result in signal contributions from carbides.

Light microscopy was also used to examine the transition zone for potential residual sealing material. Representative micrographs of the interface between the cast and additively manufactured sections, taken under two different illumination conditions, are presented in Figure 3. Given the average particle size of the ceramic filler, $D_{avg} = 118.75$ µm, no evidence of ceramic residue was observed in the bonding region.

Through iterative testing, a resin concentration of $c_{r,1} = 25$ % was determined to provide an optimal compromise between ease of manual application and removability using the ammonia solution. In contrast, higher resin contents, such as $c_{r,2} = 50$ %, significantly reduced solubility; under identical conditions, this formulation remained insoluble. During the removal process of the $c_{r,1} = 25$ % composite, the material fragmented into discrete pieces, with individual fragment sizes reaching up to $l_{max} = 10$ mm. This behavior poses a potential risk of blockage within the cooling channels.

4 Conclusion

This study presents an effective sealing method to protect internal cooling channels during LPBF repair of turbine blades. The composite material exhibited strong thermal stability and was fully removable without residue or damage to the base material. However, fragmentation during removal poses a potential risk of channel blockage, indicating the need for further refinement. Overall, this approach represents a meaningful advancement toward more sustainable and reliable turbine blade repair.

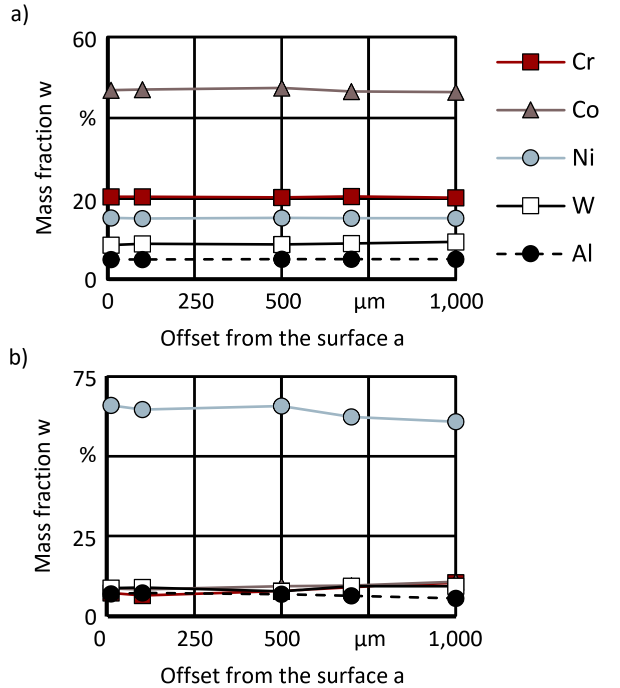

Figure 2. Elemental mass fractions determined by EDS as a function of distance from the surface: (a) additively manufactured region, (b) cast region.

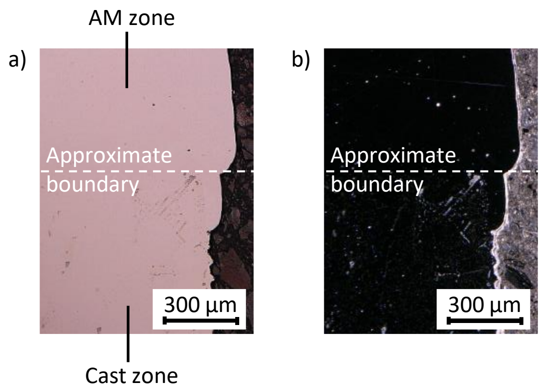

Figure 3. Light microscopy images of the bonding zone at 300x magnification under (a) coaxial illumination and (b) dark-field illumination.

References

[1] Wilson, J. M.; Piya, C.; Shin, Y. C.; Zhao, F.; Ramani, K.: Remanufacturing of turbine blades by laser direct deposition with its energy and environmental impact analysis. *Journal of Cleaner Production* **80** (2014), P. 170 – 178.

[2] Angel, N. M.; Basak, A.: On the Fabrication of Metallic Single Crystal Turbine Blades with a Commentary on Repair via Additive Manufacturing. *MDPI Journal of Manufacturing and Materials Processing* **4** (2020), P. 101.

[3] Walachowicz, F.; Bernsdorf, I.; Papenfuss, U.; Zeller, C.; Graichen, A.; Navrotsky, V.: Comparative Energy, Resource and Recycling Lifecycle Analysis of the Industrial Repair Process of Gas Turbine Burners Using Conventional Machining and Additive Manufacturing. Journal Of Industrial Ecology **21** (2017), P. S1.