ASSESSMENT OF ABD®-900AM FOR REPAIR APPLICATIONS IN TURBOMACHINERY

INTRODUCTION

ABD®-900AM is an age-hardenable Ni-based superalloy created specifically for the demands of additive manufacture (AM). The alloy was designed for an improved combination of high strength and manufacturability compared to alloys commonly used in AM. This has been confirmed by performance assessment on ABD®-900AM using laser powder bed fusion (LPBF). The printability of the alloy using LPBF shows a high resistance to cracking and ~99.9% density (Fig. 1).

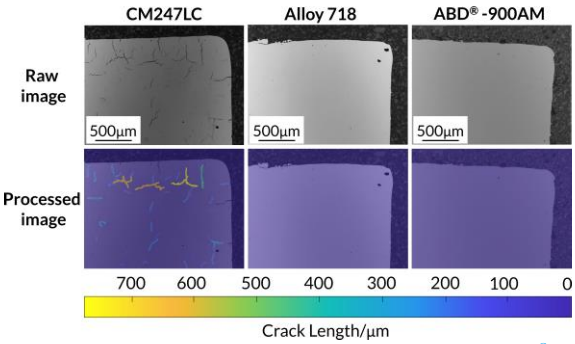


Figure 1: Crack length and distribution maps of CM247LC®, alloy 718 and ABD®-900AM printed by LPBF

The mechanical properties for ABD®-900AM has been compared with alloy 718 when using LPBF (Fig 2). At elevated temperatures >800°C the alloy provides a minimum of 30% improvement in yield stress. The creep temperature capability is improved by up to 100°C.

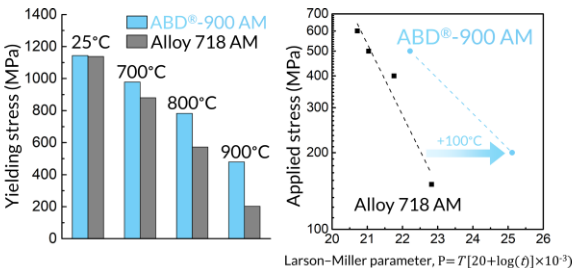


Figure 2: Mechanical property assessment for heat-treated alloy 718 and ABD®-900AM after LPBF

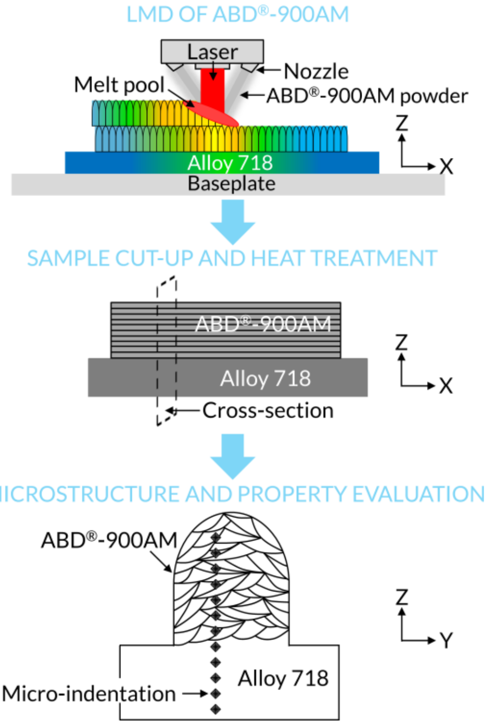
REPAIR: CHALLENGES AND OPPORTUNITIES

The Laser Metal Deposition (LMD) process is an established method for repair of superalloy components, for example repair of worn areas on compressor and turbine aerofoils. The purpose of this study was to understand the benefits of ABD®-900AM when applied in LMD. A particular focus of the study was to compare against alloy 718.

During LMD of alloy 718 Laves phase can form between dendritic cells and in the overlapping interface between two adjacent laser scanning tracks. The presence of the Laves phases is detrimental to the mechanical properties of the 718 alloy, ideally a post-deposition heat treatment (PDHT) is needed to remove these phases. However, this is not always possible for concerns which include additional processing cost or, more importantly, unacceptable distortion of the repaired component. The composition of the ABD®-900AM is designed to prevent the formation of the detrimental phases such as Laves during AM and therefore could offer the benefit to avoid PDHT. ABD®-900 is also being considered as an alternative repair materials for high strength non-weldable superalloys such as alloys 738, 939 or CM247LC®.

LMD PROCESSING TRIALS

Substrates of alloy 718 were manufactured using selective laser melting (SLM). The substrates were given a heat treatment at 980°C in vacuum for 1 hour to relieve the residual stress. The top surface of the substrate was shot peened in order to roughen the surface and improve adherence. The steps taken to evaluate ABD®-900AM in the LMD process are summarized below.



Thin-wall blocks of ABD®-900AM were built onto the substrates. A laser spot size of ~1 mm and a bidirectional scanning pattern were used. The length and the width of the build was 80 mm and 4 mm, a build height of up to 70 mm was used, example builds shown in Fig. 3.

Cross sections on the Y-Z plane were prepared for examination using optical microscopy. Samples were polished and etched using Kalling's solution to reveal the morphology of the melt pool and grains structure.

Hardness was measured using a Vickers indenter with a 1 kg load. A spacing of 3 times the indentation diagonal lengths was used to avoid the overlap of the indentation affected zones.

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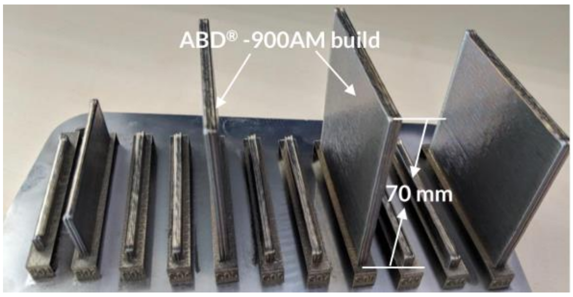

Figure 3: Alloy 718 substrates after LMD processing trials with ABD®-900AM.

CHARACTERIZATION OF LMD STRUCTURE

The microstructure of ABD®-900AM was characterised in the as-deposited condition (Fig. 4). The ABD®-900AM was dense and free from cracking. Porosity levels were measured to be less than 1% using image analysis software. The interface was free from microstructural defects and no secondary phases were observed. There was limited dilution, indicated by the sharp and clean interface. Characteristic imprints of LMD melt pools are seen.

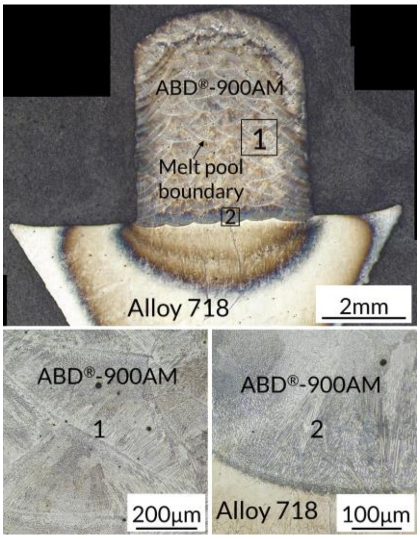

Figure 4: Microstructural assessment of an alloy 718 substrate with LMD ABD®-900AM in as-deposited condition

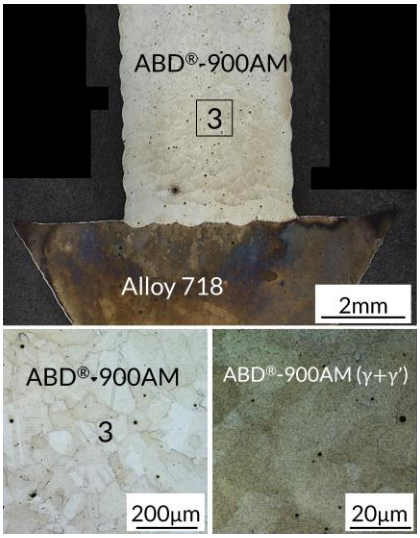

Figure 5: Microstructural assessment of an alloy 718 substrate with LMD ABD®-900AM in heat-treated condition

The substrate with LMD ABD®-900AM was given the following heat treatment (1060 °C/2hrs/air cooling (AC) → 850/8hrs/AC → 760 °C/16hrs/AC). Microstructural assessment of the heat-treated specimen showed that the alloy did not crack during post-weld heat treatments (Fig. 5). There was also no increase in porosity. The interface remained sharp and clean, there was no evidence of microstructural defects or secondary phase formation. The grain structure of ABD®-900AM shows a recrystallised microstructure, indicated by the equiaxed grains and a substantial amount of annealing twins. The heat treatment resulted in γ/γ' microstructure, determined using scanning electron microscopy (SEM).

HARDNESS ASSESSMENT OF REPAIR

In the as-deposited condition ABD®-900AM has a much higher hardness than as-deposited alloy 718 (~70HV) tested under similar conditions (Fig. 6). The hardness is equivalent to wrought 718. The hardness measurements indicate that tensile and wear performance of the as-deposited ABD®-900AM should exceed those of as-deposited 718 and be near-equivalent to wrought 718. This is of significant benefit when it is not possible to apply a PDHT after repair of alloy 718 components.

After heat-treatment the hardness of the ABD®-900AM increased by ~150 HV. The hardness of heat-treated ABD®-900AM is ~30% higher than that of the wrought 718 , suggesting that in areas where ABD®-900AM was used for repair of 718 components thermal exposure (either through heat-treatment or in service operation) would increase the strength and wear resistance relative to the substrate material.

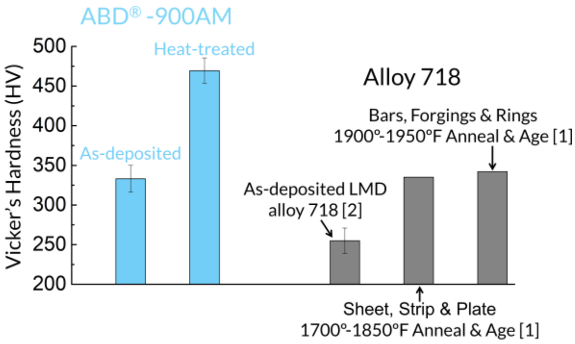

Figure 6: Comparison of the hardness between LMD ABD®-900AM and Alloy 718.

CONCLUSIONS

1. Thin walled ABD®-900AM blocks up to 70 mm high were successfully built up on alloy 718 substrates using LMD.
2. The as-deposited and heat-treated ABD®-900AM was dense and crack free, without microstructural defects in the bulk and at the substrate interface.
3. The as-deposited ABD®-900AM shows a hardness value comparable to wrought 718 , suggesting the as-deposited ABD®-900AM matches the wrought 718 in strength.
4. The hardness of heat-treated ABD®-900AM is ~30% higher than that of the wrought 718, suggesting that the LMD ABD®-900AM with heat treatment could significantly outperform alloy 718 in strength.

[1] Inconel alloy 718 - Special Metals, http://www.specialmetals.com/assets/smc/documents/inconel_alloy_718.pdf
[2] Erica L. Stevens, Jakub Toman, Albert C. To, Markus Chmielus, Variation of hardness, microstructure, and Laves phase distribution in direct laser deposited alloy 718 cuboids, Materials & Design, 119 (2017), pp. 188-198