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Microstructural and tensile characterization of Inconel 718 laser coatings for aeronautic components

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ABSTRACT

The suitability of the laser cladding technique for manufacturing and repairing aeronautic components of Inconel 718 was evaluated. Multilayer coatings were deposited on Inconel 718 plates, using a continuous wave Nd:YAG laser. The microstructure of the laser cladding samples was investigated using optical and scanning electron microscopy and microhardness profiles were measured after different heat treatment stages. Finally, tensile tests were carried out on fully aged samples extracted from a massive multilayer coating. It was proven that the resulting coatings satisfy the industrial requirements for aeronautic applications, with mechanical properties well above the minimum specified values and with no detrimental phases or precipitates left after the heat treatment.

1. Introduction

Nowadays, one of the major aeronautic industry interests is to reduce cost during the different manufacturing stages of a component, starting from the conceptual design and prototyping, manufacturing and finally repair and maintenance works. More flexible and efficient manufacturing processes are necessary for reducing production time and improving performance and service life of different components: turbine discs, blades, etc. This aspect becomes especially important when the components are made of nickel superalloy materials like Inconel 718.

Inconel 718 is a nickel-based heat resistant precipitation hardenable alloy, commonly employed in advanced structural applications, for example in the aeronautic industry, where it is used as a high-performance and high-temperature material. Inconel 718 is also a hard to mold and machine material due to its fast deformation hardening, and it presents a good weldability due to its relatively slow precipitation strengthening kinetics [1]. However, this nickel alloy is rather expensive, what increases the manufacturing processing costs, mainly during the machining and finishing operations, due to the amount of generated wasted material.

The laser metal deposition or laser cladding technique can reduce the quantity of material employed in the manufacturing or repairing of a component: when the part is manufactured by machining, the starting point is a large forged pre-form, being necessary to remove a sizable quantity of material until the final geometry is reached. Laser cladding is a laser additive technique used primarily in the surfacing of metallic components to provide increased wear and corrosion resistance [2]. The technique is being employed successfully in numerous applications such as manufacturing of dies and molds [3,4], medical implants [5], reinforcing of gears, axes, etc. The principle behind the process consists in the formation of a fully dense, metallurgically bonded coating by melting a coating alloy onto the surface substrate with a laser beam normal to the irradiated surface. The coating material is usually delivered to the melt pool in powder form by means of a carrier gas. A high variety of materials can be deposited on a substrate by powder injection. Covering extended areas is possible by overlapping single laser tracks and also multilayer cladding is possible, in order to achieve higher coating thicknesses. Advantages of the method include low dilution, minimal heat input and small heat affected zones, limited distortion and precise dimensional control of the cladding tracks. Compared to conventional deposition techniques such as Tungsten Inert Gas (TIG) welding, plasma spray or High Velocity Oxygen Fuel (HVOF), the generated coatings are free of pores, micro-cracks and bonding defects and have a good adherence to the substrate.

Concerning the manufacturing of aeronautic parts by means of the laser cladding technique, it is possible to begin from scratch or from a smaller pre-form, and start adding layers of material up to the final geometry. As no material is eliminated, the amount of necessary raw material is minimized, so the technique results

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in an environmental impact reduction as well as a moderation in costs, as opposed to competing techniques. This technique can also be used as a repairing tool, thereby extending service life on parts that otherwise would have to be replaced.

The use of the laser cladding technique for the deposition of nickel based superalloys, particularly Inconel 718, has generated certain interest, both in industry and in academia. For instance, some authors, such as Liu et al. [6], Qi et al. [7], Zhao et al. [8] and Blackwell [9], have presented works related to the microstructure and mechanical properties of laser cladded Inconel 718, in the "as-clad" state and after different heat treatments, using a CO_2 laser source. Of particular practical interest is a second work by Qi et al. [10], where an adaptive toolpath deposition scheme for the repair of turbine compressor airfoils is developed.

In order to validate the technology, i.e. to determine if it is really applicable to the manufacturing of high-value and high-performance components, it is necessary to verify that the properties of the laser cladded material are equivalent to the ones obtained by conventional manufacturing processes and therefore satisfy the specifications for the component. This has been the objective of the present work: to study the properties of laser cladded Inconel 718 to verify whether the obtained properties satisfy the industrial requirements for aeronautic applications. For this purpose, the properties of Inconel 718 base material and Inconel 718 coatings in the "as-clad" state, in solution treated state and in age hardened state were studied. In the present study the coatings were deposited by means of a continuous wave fiber coupled Nd:YAG laser.

2. Material and experimental procedure

2.1. Material: Inconel 718

Wrought Inconel 718 plates of 200×100 mm and a thickness of 20 mm were used as the substrate material. The samples surface was machined before the laser cladding tests were carried out. An argon gas atomized Inconel 718 powder, supplied by FST (Flame Spray Technologies) with particle size between 45 and 90 μm (Fig. 1), was used as the coating material. The chemical composition of the substrate and the coating alloy, obtained experimentally, is shown in Table 1.

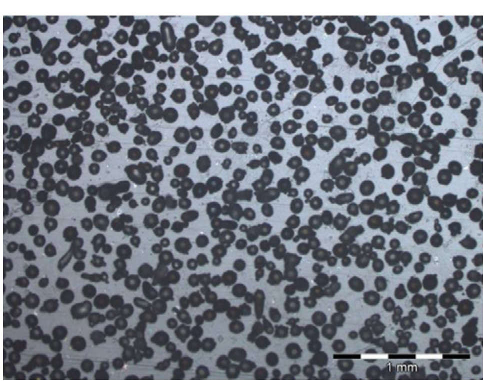

Fig. 1. Gas atomized, spheroidal Inconel 718 powder.

2.2. Industrial requirements

Below are presented the main industrial requirements for a laser manufactured or repaired Inconel 718 generic component. The minimum values for the relevant magnitudes are shown, to be obtained via tensile testing at ambient temperature. Table 2

It is also of critical importance that the coatings satisfy a certain number of metallurgical requirements, those listed in Table 3.

It is also deemed important to minimize the amount of Laves phase present in the coatings, although an exact admissible fraction value could not be found.

2.3. Laser cladding and heat treatments

The laser cladding was conducted using a 2.2 kW diode pumped continuous wave Nd:YAG laser. The laser beam was guided to the working area by a 0.6 mm diameter circular fiber connected to a laser head with an optical system, able to provide a defocused 2.1 mm circular spot with a Gaussian irradiance profile at the selected working distance. A powder injection system was used to deliver alloy powders into the melt pool through a discrete laser cladding nozzle. The powder was preheated to 75 °C prior to deposition. Argon was used both as carrier and as coaxial shielding gas, to prevent surface oxidation. Multilayer coatings with desired overlap ratio were generated, obtaining a square shaped structure of dimensions $10 \times 10 \times 6$ mm. Each layer was deposited with a bidirectional strategy, in which each layer is deposited perpendicularly to the previous one. This strategy provides a uniform and continuous deposition, with idle time only between subsequent layers. A preliminary parameterization was performed, in order to obtain well shaped laser clads. The most relevant processing parameters are summarized in Table 4.

The as-deposited samples were heat treated performing a solution treatment at 980 °C during 1 h and cooled in air at ambient temperature, followed by a double aging, at 720 °C during 8 h with a subsequent furnace cooling, and at 620 °C during 8 h with a subsequent air cooling.

Table 2
Mechanical requirements for an Inconel 718 component.

Magnitude	Ultimate tensile strength (MPa)	0.2% Yield strength (MPa)	Elongation (%)
Specification	1079	871	2.5

Table 3
Structural requirements for an Inconel 718 component.

Defect	Specification
Cracks	NO
Start or end crater	NO
Oxidation	NO
Isolated porosity	Max. 0.5 mm diameter
Grouped porosity	Max. 0.5 mm de diameter Max. number of grouped defects: 6

Table 1
Chemical composition (wt%) of the studied materials.

Material	Ni	Fe	Cr	Mo	Nb	Ti	Al	Co	C	Si
Substrate	51.70	20.20	18.10	3.00	5.22	0.96	–	–	0.02	0.10
Coating powder	53.25	17.69	19.34	3.08	4.99	0.89	0.44	0.15	0.05	0.04