AGEING OF SINGLE CRYSTALLINE LASER DEPOSITED RENÉ N4 NICKEL SUPERALLOY

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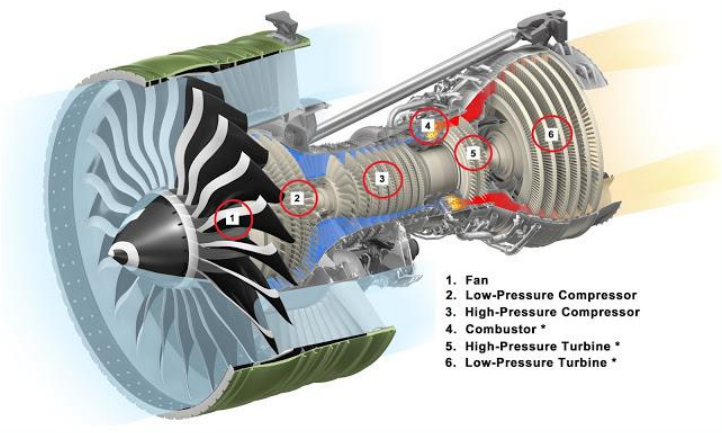
Introduction



Airplane turbine engine schematic [1].

Advances in materials engineering have been crucial to the development of modern airplanes by enabling higher operating temperatures and longer service lives of the jet engines

The greatest challenge is the hot section of gas turbine engines

[1] Electrical Parts (2019). Aircraft Turbine Engine Parts. [online] Elec-page.blogspot.com. Available at: http://elec-page.blogspot.com/2016/07/aircraft-turbine-engine-parts.html [Accessed 20 Aug. 2019].

Introduction

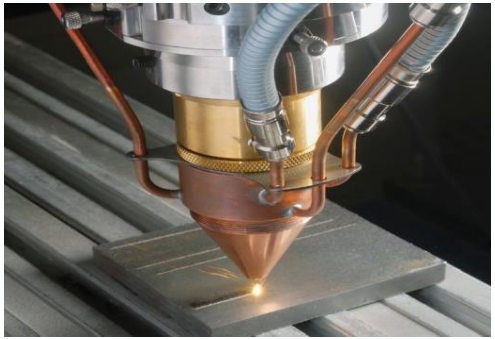
Ni-based superalloys:

- Withstand temperatures as high as 90% of their melting point (~1300 ºC)
- Outstanding thermal fatigue and creep resistance when single crystalline

The drawback of single crystalline parts is the difficulty in repairing them while maintaining the same microstructure

Laser metal deposition:

- Highly localized
- Low quantity of material required
- By controlling solidification, epitaxial dendritic single crystal deposits can be produced



Laser metal deposition setup [2].

[2] VarioClad – Laser Metal Deposition with Variable Spot Sizes – Brochure – Fraunhofer ILT. (n.d.). Retrieved April1 ,2019, from https://www.ilt.fraunhofer.de/en/media-center/brochures/brochure-Varioclad-Laser-Metal-Deposition-with-Variable-spot-sizes.html

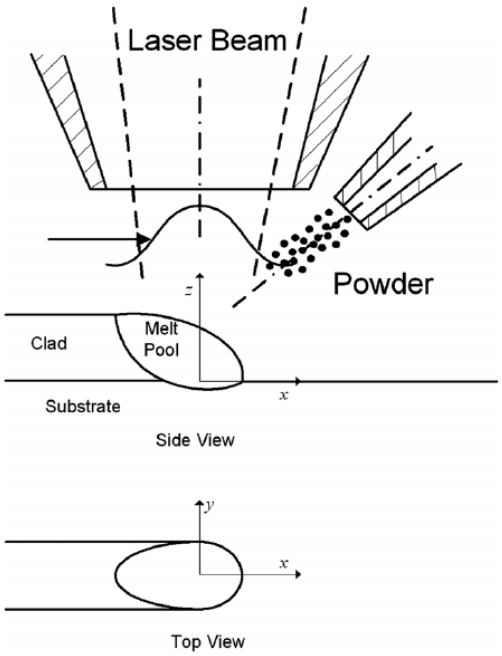
Laser Metal Deposition (LMD)

Processing parameters:

- Laser power
- Scanning speed
- Powder feed rate

The processing parameters, and thus the energy transfered to the substrate, define the shape of the melt pool

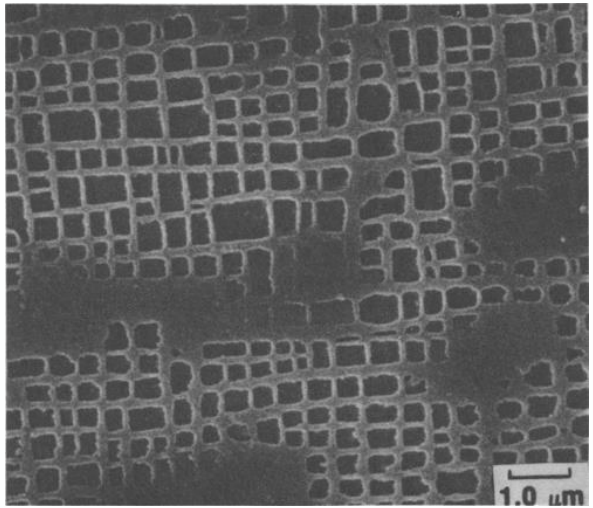
The shape of the melt pool determines the growth velocity of the dendrites



Laser metal deposition and melt pool shape schematic [3].

[3] A. Fathi, E. Toyserkani, A. Khajepour, and M. Durali, “Prediction of melt pool depth and dilution in laser powder deposition,” *J. Phys. D. Appl. Phys.*, vol. 39, no. 12, pp. 2613–2623, 2006.

High temperature superalloys microstructure - γ/γ' microstructure



Cuboidal γ' Ni_3Al phase distributed in γ phase matrix for a first generation superalloy [4].

Cuboidal γ' Ni_3Al / Ni_3Ti precipitates distributed homogenously in a γ phase matrix

Dislocations / precipitates interaction

↓

Strengthening

Other phases: Carbides, in the presence of C, and Topologically closed packed (TCP) phases

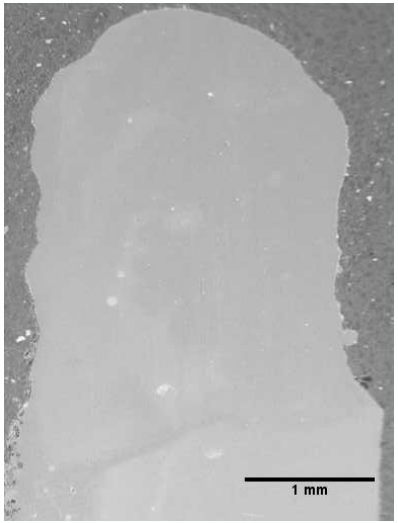
[4] M. V. Nathal, "Effect of initial gamma prime size on the elevated temperature creep properties of single crystal nickel base superalloys," Metall. Trans. A, vol. 18, no. 11, pp. 1961–1970, Nov. 1987.

Laser metal deposition of René N4 on N5

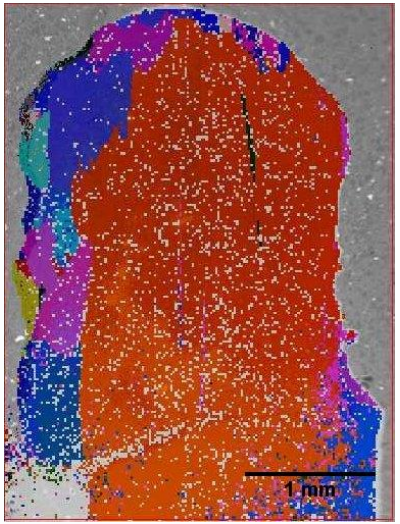
Deposition on a <100> plane of the sample

Parameters:

- Laser beam power: 500 W
- Powder feed rate: 5.14 g min^{-1}
- Scanning speed: 4 mm s^{-1}
- Spot diameter: 3 mm



Five consecutive René N4 layers on René N5 substrate.



EBSD analysis of five consecutive René N4 tracks on René N5 substrate.

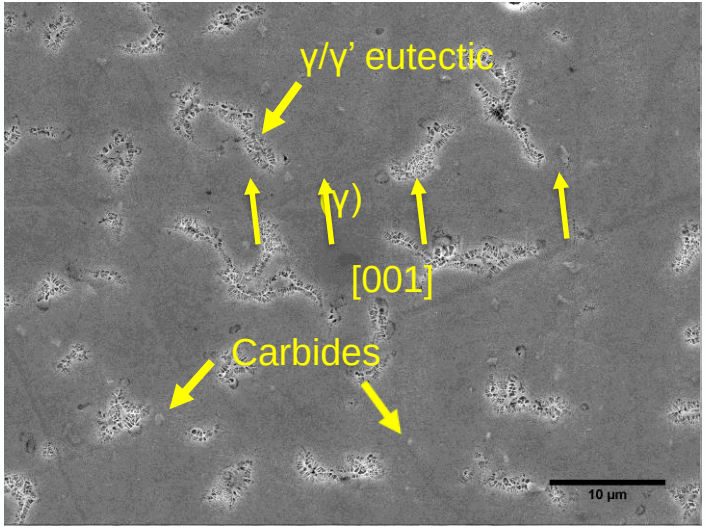
As-deposited René N4 superalloy microstructure

Dendritic microstructure with orientation [001]

The dendrites are composed of (γ) solid solution with interdendritic γ/γ' eutectic and carbides

In order to obtain the γ/γ' microstructure a post-deposition heat treatment is required. This heat treatment may comprise two steps:

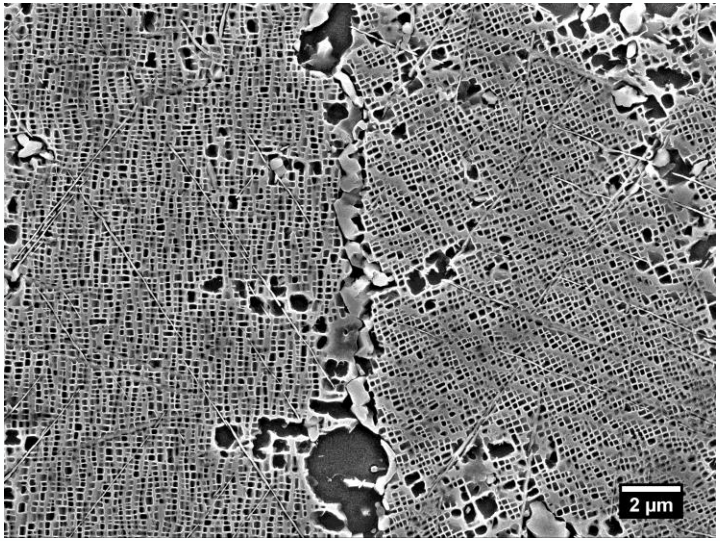
- Solution heat treatment in order to homogenize the distribution of the elements across the part (due to dendritic growth there is segregation)
- Ageing to precipitate the γ' phase with a suitable shape and size



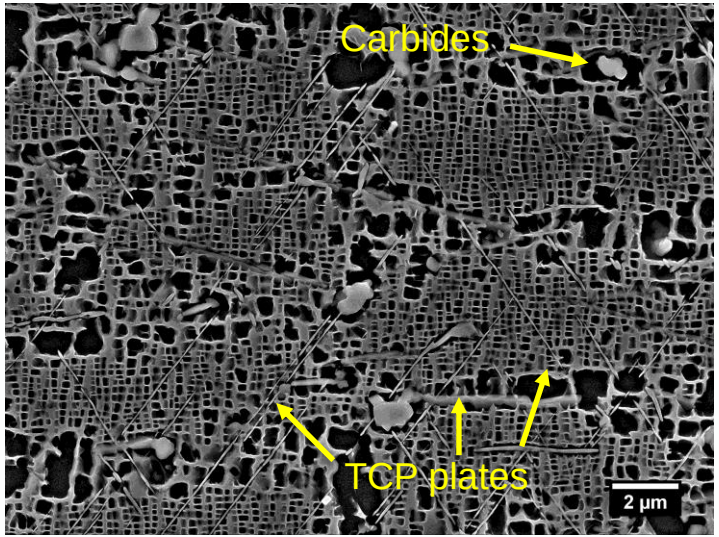
Microstructure of the as-deposited track

Ageing for 2 h at 1050 ºC with solution treatment at 1265 ºC for 1 h

High uniformity and orientation with a higher amount of TCP phase plates



1 h at 1265 ºC



1 h at 1265 ºC other area

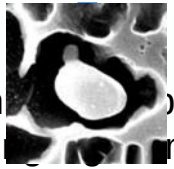
Microstructure formation and impact on properties

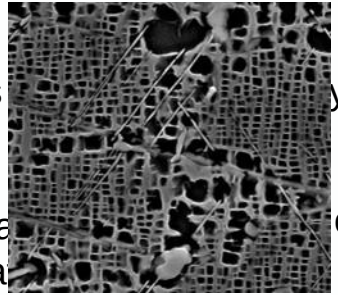
René N4 composition and solid/liquid partition coefficients (gathered from literature)

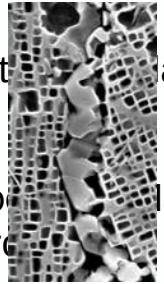
Element	Cr	Co	Al	Ti	W	Mo	Ta	C	B	Nb	Hf	Ni
Wt %	9.79	7.39	4.18	3.48	5.91	1.48	4.73	0.06	0.004	0.49	0.13	Bal.
$k_{s/l}$	1.07	1.06	0.87	0.71	1.26	1.07	0.76	0.3	-	0.24	-	-

All γ' forming elements (Al, Ti and Ta) segregate to the liquid, leading to higher volume fraction in the interdentritic regions

C, Nb, Ta, Ti segregate to interdendritic regions → Formation of carbides







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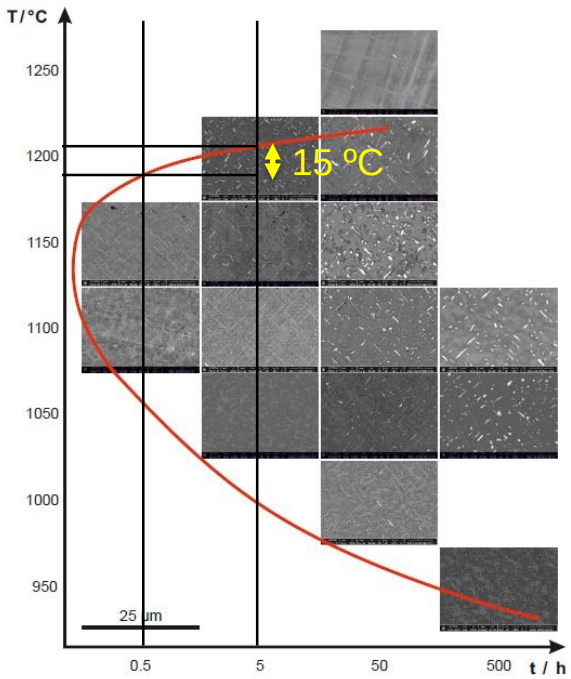
Microstructure formation and impact on properties

Effect of TCP phases on material properties:

- Depletion of refractory elements from the γ solid solution phase
- Crack initiation zones



TTT diagram for TCP phases [5]

[5] Matuszewsky, K. (2016). Precipitation of Topologically Close Packed Phases in Ni-base Superalloys – the Effect of Re and Ru (Doctoral dissertation)

Conclusions and further work

- Epitaxy is attainable over single crystalline areas of the substrate
- A two-step heat treatment is required to obtain a suitable microstructure, for example:
  1. Solution heat treatment at 1265 ºC for 1 h
  2. Precipitation step at 1050 ºC for 2 h
- Optimization of the heat treatment is still necessary in order to supress the formation of the TCP phase plates
  - Increase solution heat treatment temperature
- A detailed study of the transformations kinetics is being performed

Thank you for your attention

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