Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Chimica e dei Materiali

«Effect of laser powder bed fusion process parameters on microstructural characteristics of Ni-Cr based alloy 625»

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INTRODUCTION

This study aims to identify how the microstructural characteristics of alloy 625 produced by laser-powder bed fusion vary as layer thickness and scanning strategy change, both before and after heat treatment.

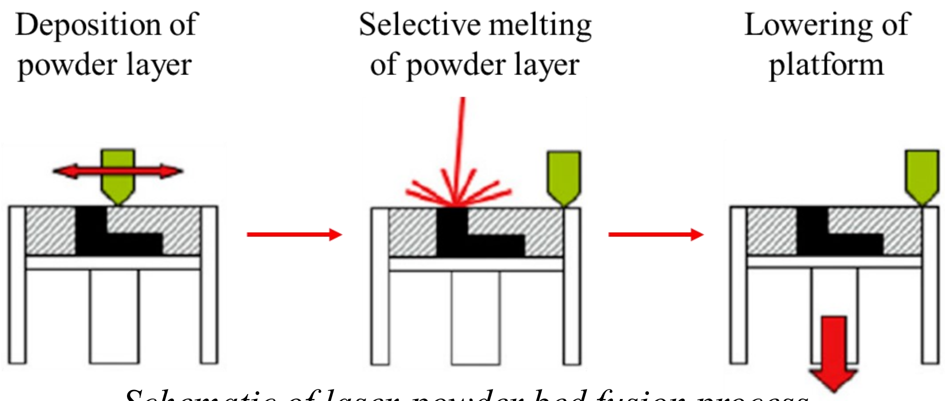
Alloy 625 is a nickel-chromium-molybdenum-based superalloy that exhibits high mechanical strength and outstanding corrosion resistance.
The main uses of this alloy involve chemical and petrochemical facilities and especially nuclear water reactors, for resistance to pressurized water at high temperatures.

Weight %	C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Co	Fe	Al	Ti
Min						20	58	8	3.15				
Max	0.1	0.5	0.015	0.015	0.5	23		10	4.15	1	5	0.4	0.4

Chemical composition of Alloy 625

INTRODUCTION

Laser-powder bed fusion (L-PBF) is an additive manufacturing technique used to produce metal components.



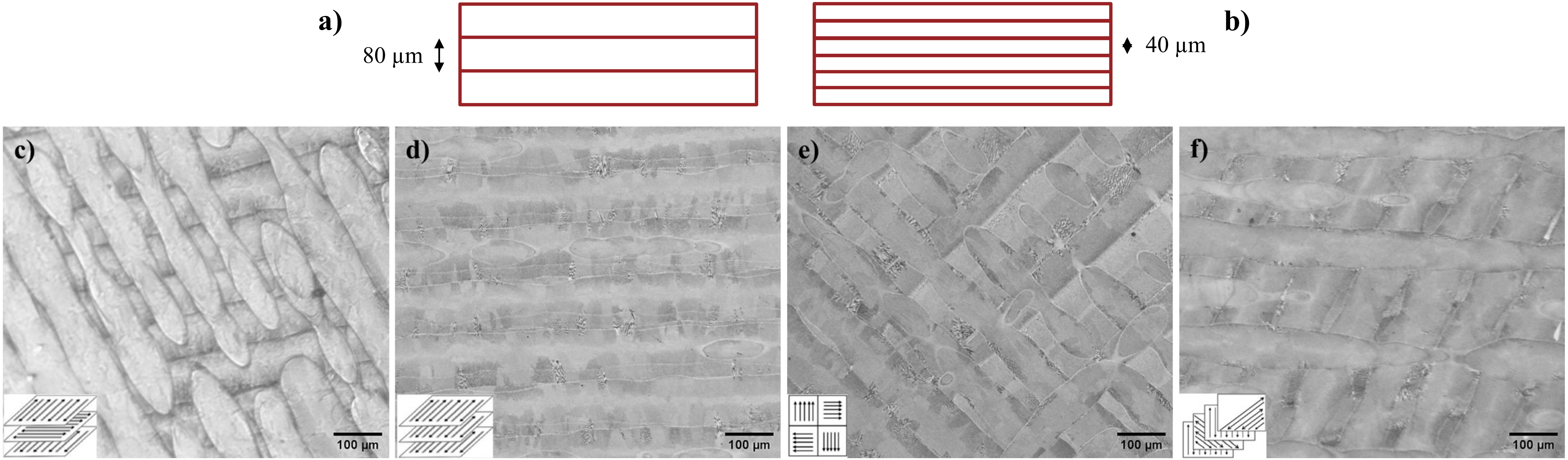
Schematic of laser-powder bed fusion process

The parameters of L-PBF that can be adjusted in order to achieve a higher quality of the final product are:

- **Laser Power**
- **Scanning Speed**
- **Hatch Spacing**
- **Particles Size**
- **Layer Thickness**
- **Scanning Strategy**

Samples Parameters

The parameters used for producing the specimens are layer thicknesses of 80 and 40 microns and scanning strategies 'NoPat', 'NoPat 180', 'Chess', and 'Stripes'.

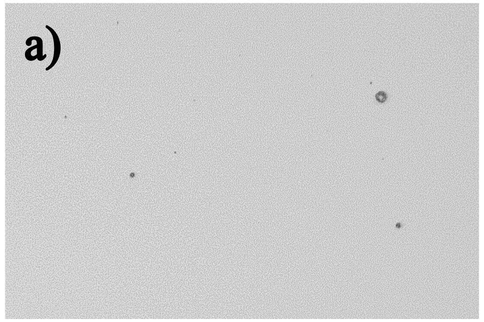


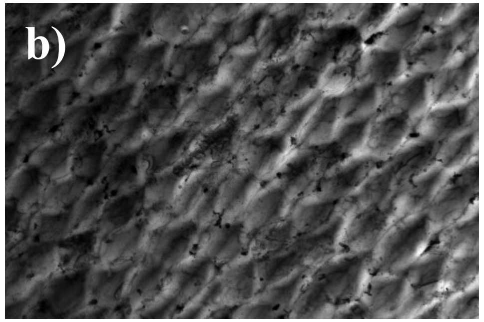
Layer thicknesses of 80 (a) and 40 microns and laser tracks of 'NoPat' (c), 'NoPat 180' (d), 'Chess' (e), and 'Stripes' (f) scanning strategies

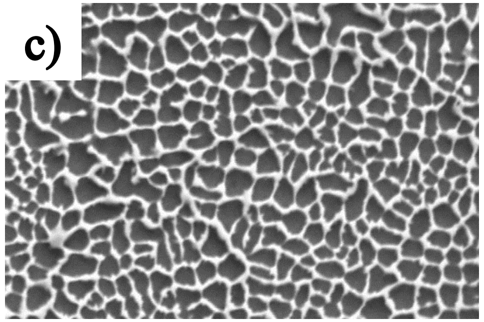
TESTS PERFORMED

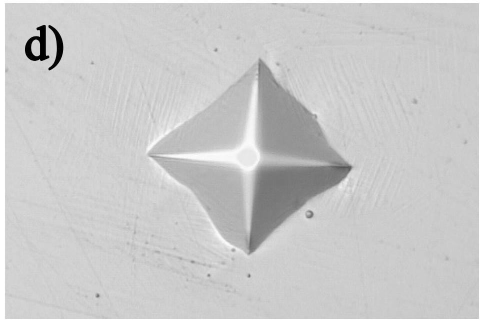
To analyze the microstructural changes induced by parameter variation, the following tests were performed on each sample, before and after stress-relieving heat treatment:

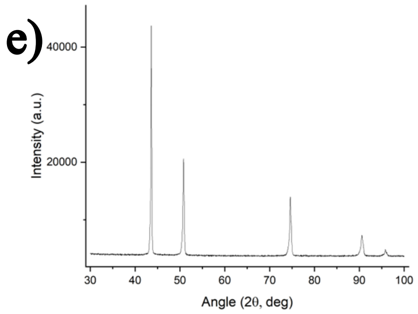
- a) Pore Surface Area Analysis
- b) Microstructural Characterization
- c) Subgrain Width Analysis
- d) Vickers Hardness Test
- e) X-Ray Diffraction







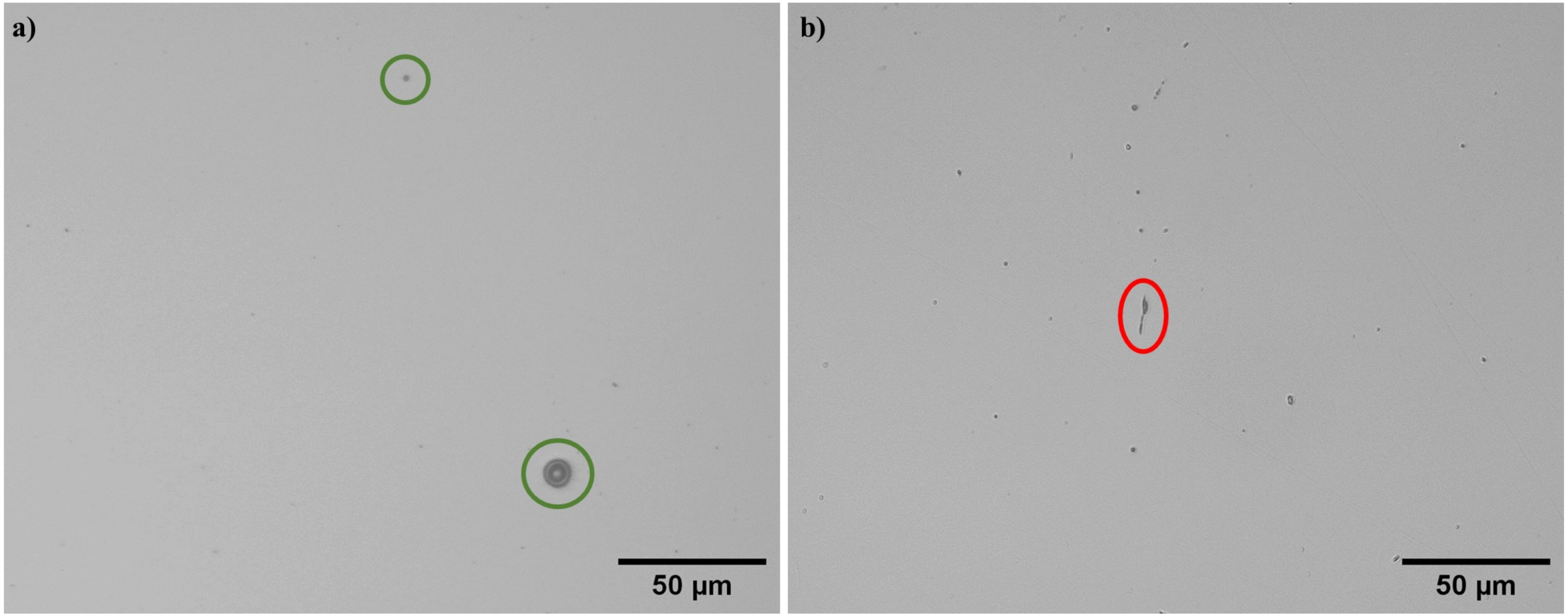




RESULTS: PORE SURFACE AREA ANALYSIS

Through surface analysis, two different types of porosity were identified:

- Gas Porosities, having a spherical shape
- Lack-of-fusion Porosities, having an irregular and elongated shape



Gas porosities (a) compared to lack-of-fusion porosities (b)

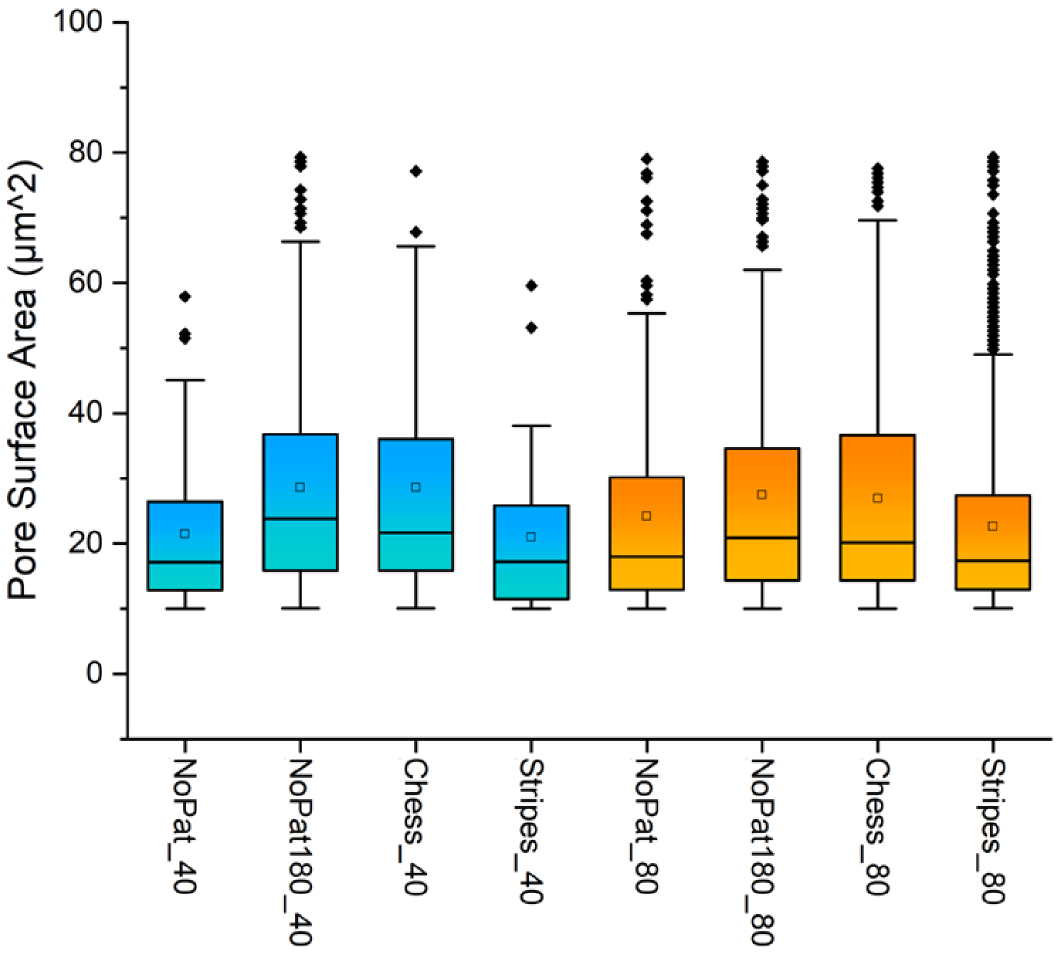
RESULTS: PORE SURFACE AREA ANALYSIS

The pore size is shown to be slightly larger in the case of the 'NoPat 180' and 'Chess' strategies.

This is due in the case of 'Chess' to an increased splash of metal particles caused by the concentration of the laser tracks.

For 'NoPat 180' the larger pore size is due to the smaller remelting occurring in certain areas of the sample.

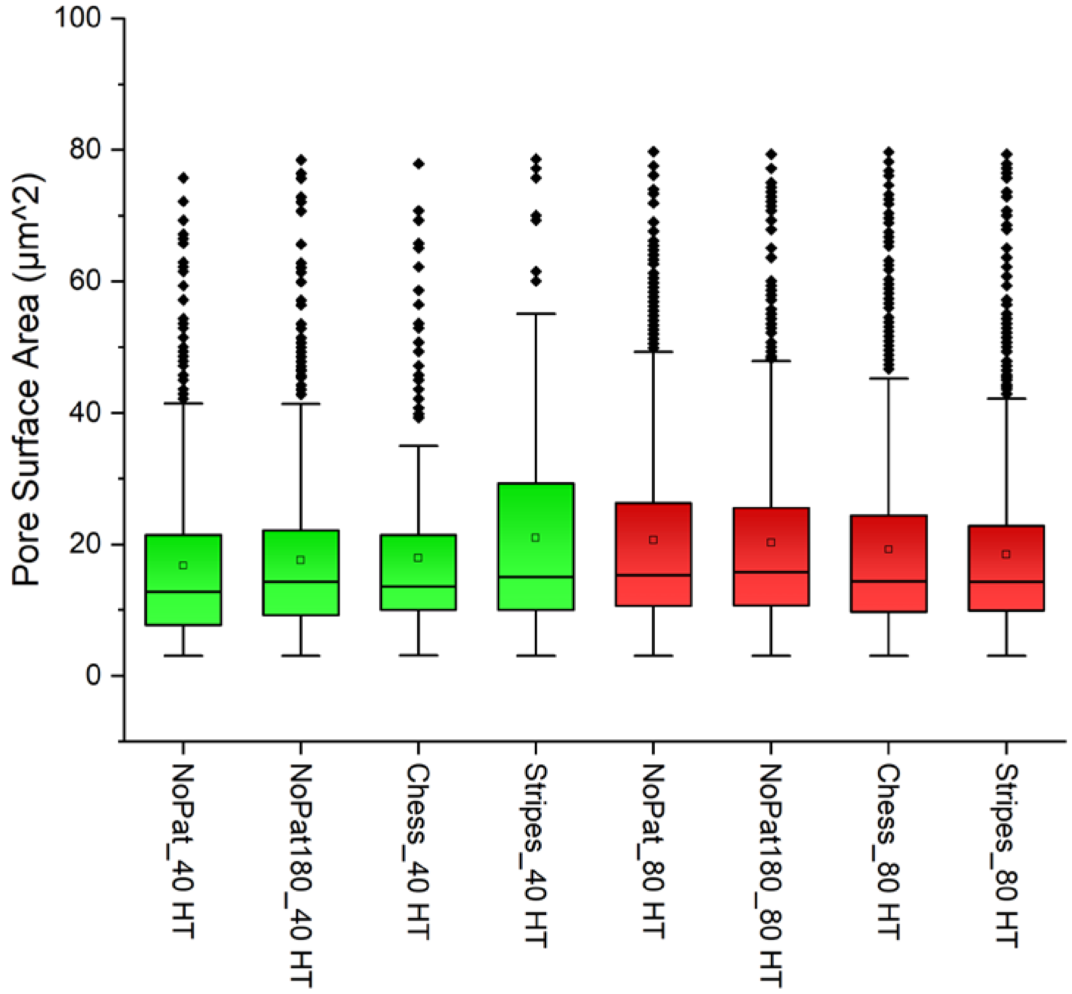
No relevant differences are observed for the two different layer thicknesses.



Pore surface area distribution for each sample

RESULTS: PORE SURFACE AREA ANALYSIS

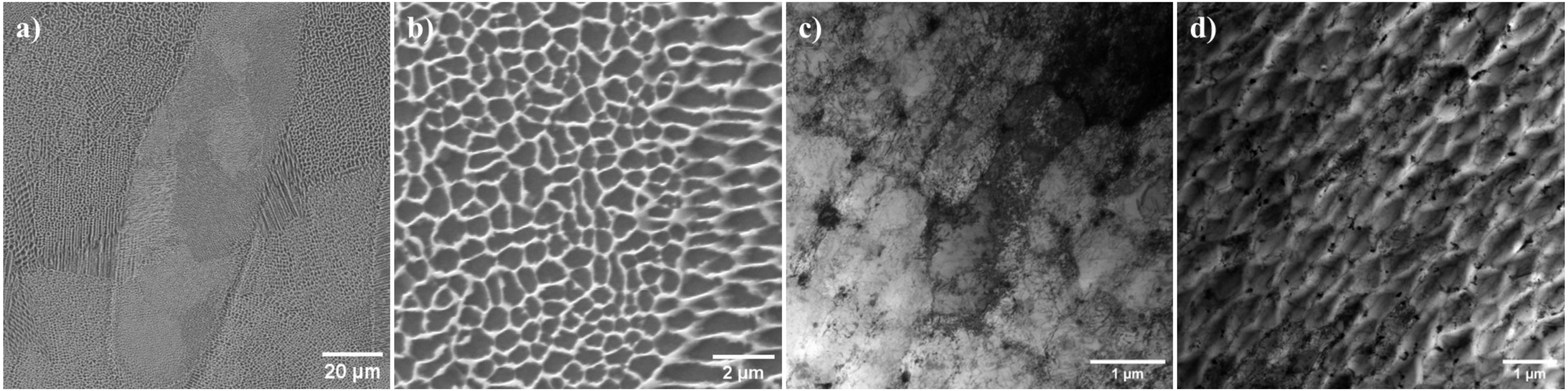
Heat treatments lead to a uniformity of pore size values across all samples, suggesting the elimination of variations introduced by the use of different scanning strategies.



Pore surface area distribution for heat-treated samples

RESULTS: MICROSTRUCTURAL CHARACTERIZATION

SEM analysis allows observation of the typical cellular structure of the superalloy. The high cooling rate associated with L-PBF does not allow the formation of secondary phases detectable through SEM analysis. To observe smaller carbides with sizes below 1 micron, TEM analysis is required.



Microstructure of Alloy 625 observed through SEM analysis (a, b) and through TEM analysis (c, d)

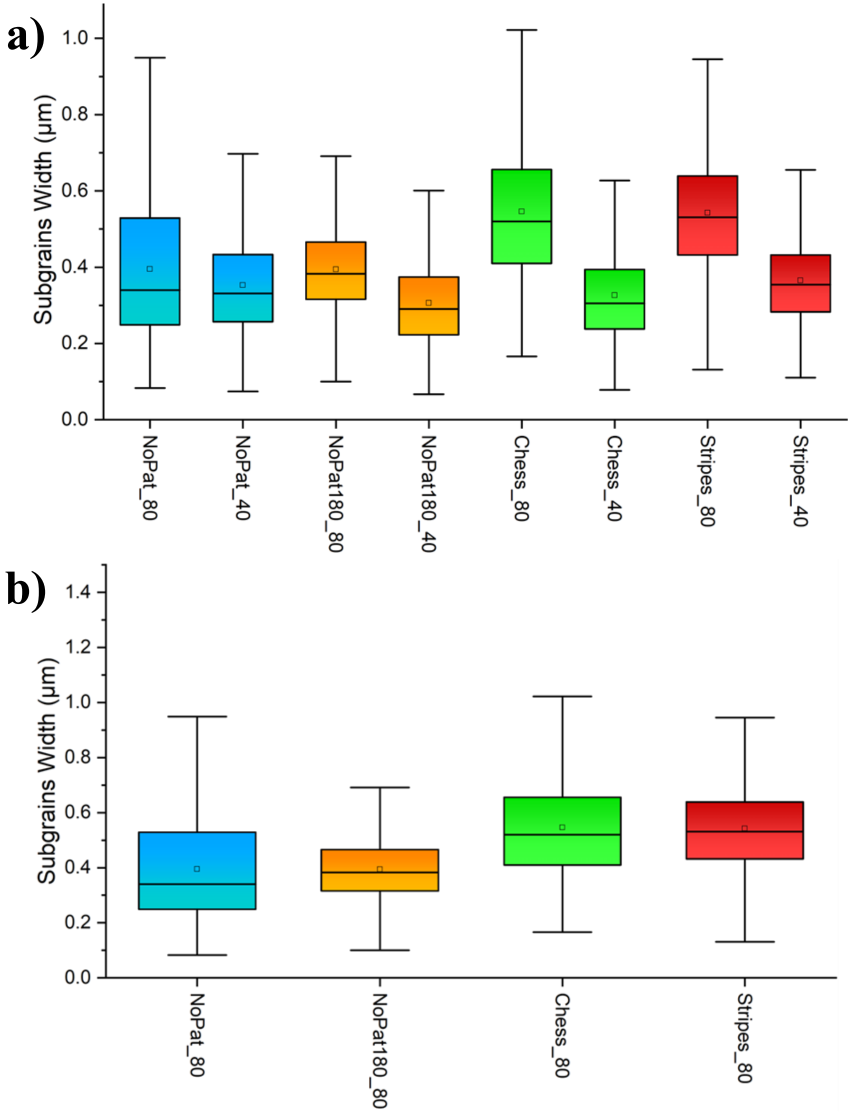
RESULTS: SUBGRAIN WIDTH ANALYSIS

Two factors influence grain size: cooling rate and remelting.

Samples with higher layer thickness show larger subgrains due to the slower cooling rate.

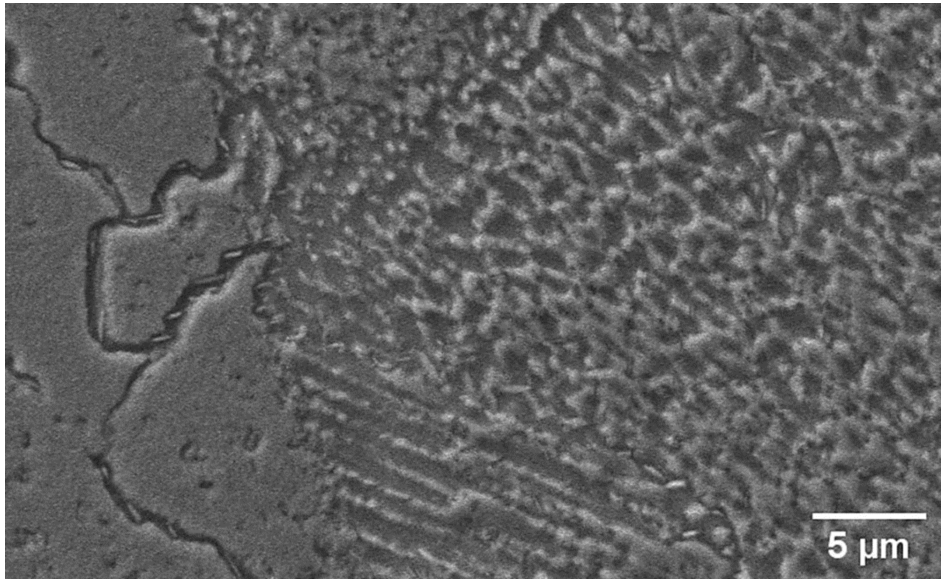
Among the samples with the same layer thickness, the cooling rate turns out to be the same for all samples. Thus, the differences between the various scanning strategies can be attributed to remelting.

‘Chess' and ‘Stripes' show smaller subgrains as the greater overlap of the laser tracks leads to higher remelting.



Comparison of subgrain width for different layer thicknesses (a) and for different scan strategies (b)

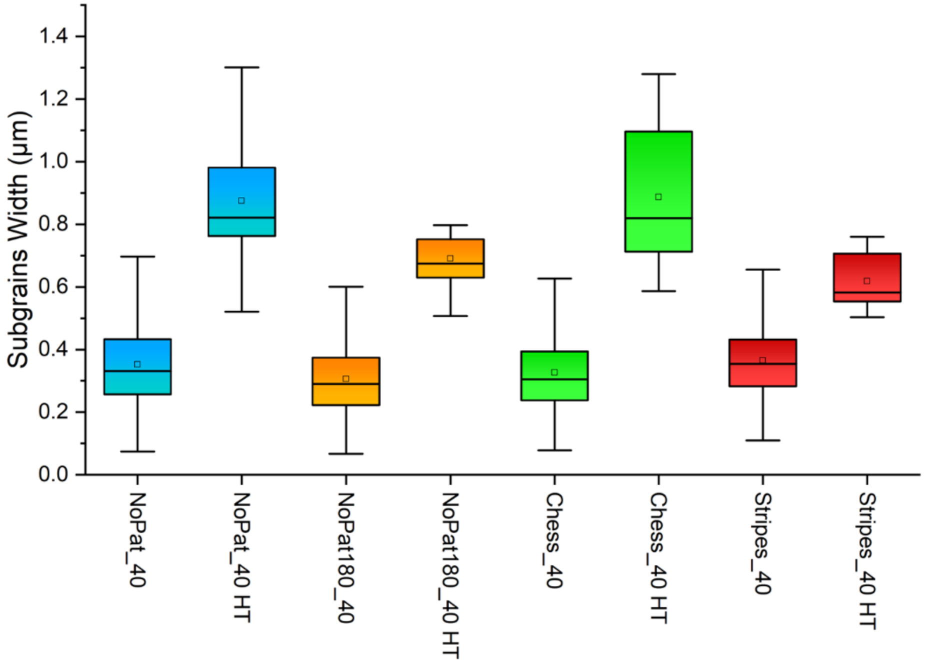
RESULTS: SUBGRAIN WIDTH ANALYSIS



Partial dissolution of subgrain boundaries

Heat treatments strongly influence the microstructure of the alloy by going to dissolve the subgrain boundaries partially in order to reach a lower-energy thermodynamic state.

The remaining subgrains are significantly larger in size than those of the non-heat-treated samples.



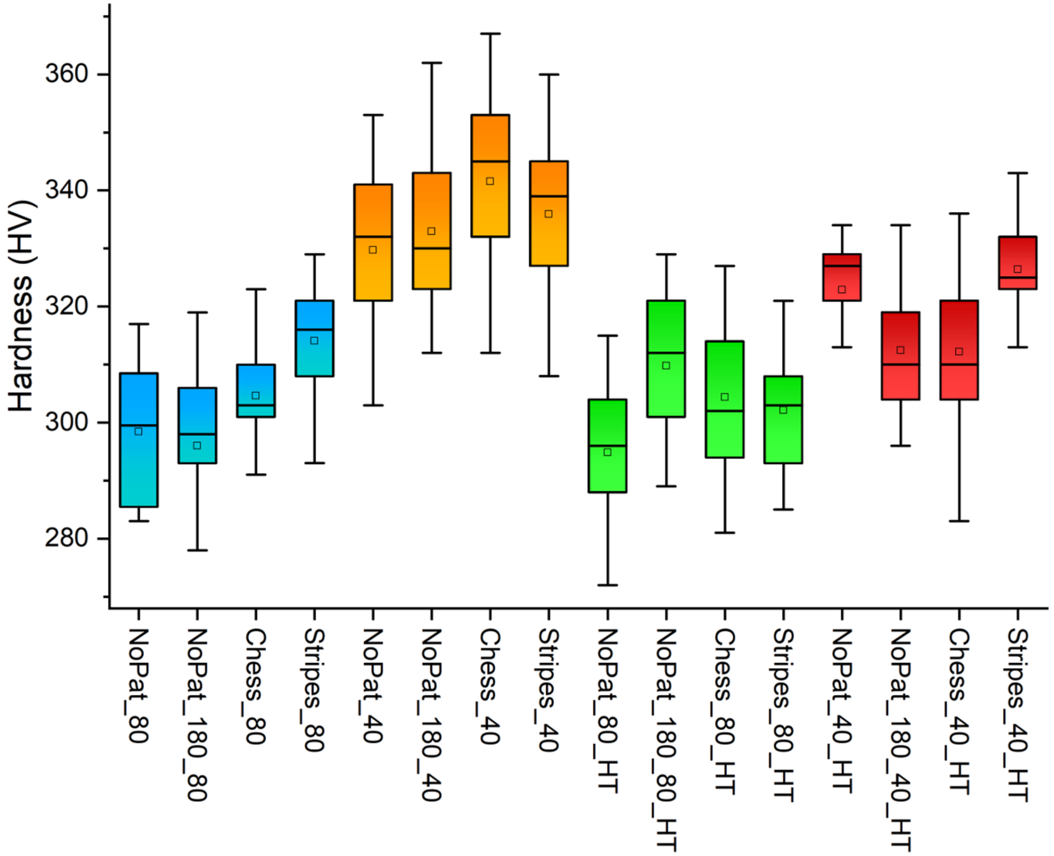
Comparison of the remaining subgrains with those of non-heat-treated samples

RESULTS: HARDNESS

There are no significant variations in hardness values among samples with different scanning strategies, except for slightly higher values for the 'Chess' and 'Stripes' strategies.

However, an inverse correlation is observed between hardness and layer thickness. As the layer thickness increases, there is a slight decrease in hardness.

Heat-treated samples show equal or lower hardness than non-heat-treated samples.



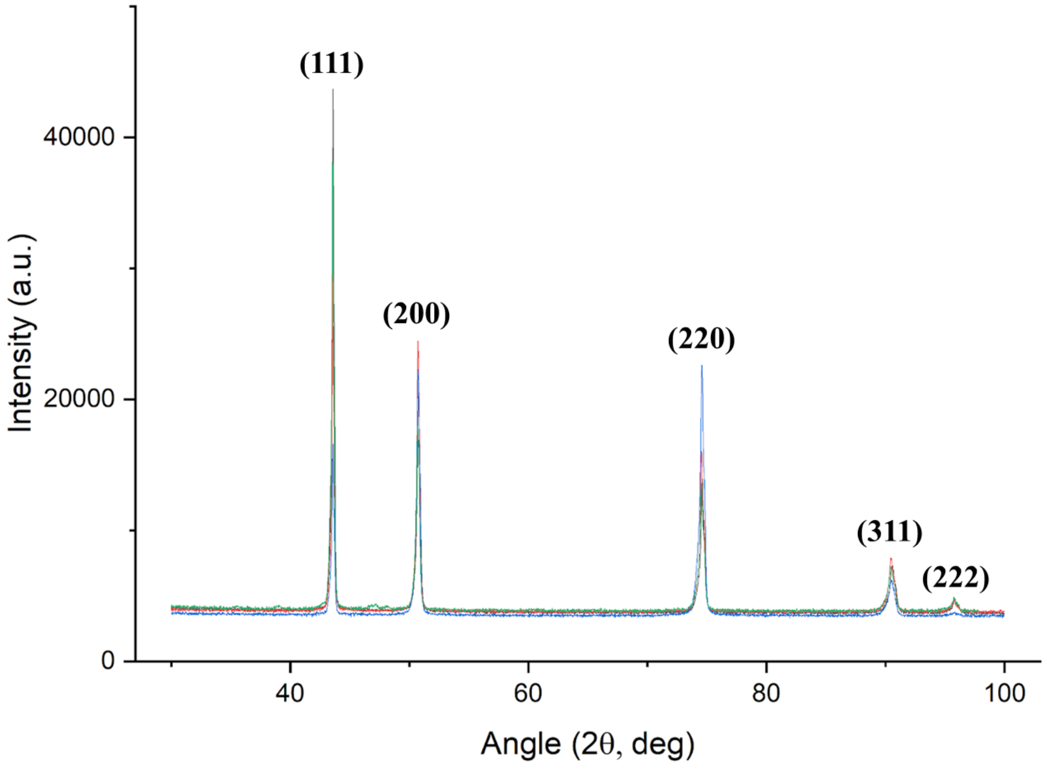
Hardness values for samples both before and after heat treatment

RESULTS: X-RAY DIFFRACTION

The diffraction spectra of the various samples show peaks corresponding to the matrix (γ phase).

No broadening of the peaks suggests that the main microstructural differences are observed with the other analyses performed

The only variation observed among the samples is the difference in peak heights, which can be attributed to the use of different scanning strategies. The diffraction spectra of the various samples



Comparison of XRD patterns for different scan strategies

CONCLUSIONS

- Regarding the pore surface area, the 'NoPat 180' and 'Chess' strategies show slightly larger pore sizes than the others, while the pore surface area values of the heat-treated samples are almost identical.
- The width of the subgrains turns out to be smaller for the ‘NoPat' and ‘NoPat 180' strategies, compared to ‘Chess’ and ‘Stripes’. However, the most significant variations in subgrain dimensions are observed when altering the layer thickness. Specifically, increasing the layer thickness leads to the formation of larger subgrains.
- Heat-treated samples show partial dissolution of subgrain boundaries, with the remaining subgrains reaching significantly larger sizes than those of non-heat-treated samples.
- Samples showing higher hardness turn out to be those with layer thickness of 40 microns. The same applies to heat-treated ones but the hardness is significantly lower.
- X-ray diffraction does not highlight any microstructural differences except for preferential crystallographic orientations as the scanning strategy changes.

GRAZIE PER L'ATTENZIONE