COMUNICAÇÃO TÉCNICA

Nº 178656

Microstructure of a heat-treated 420S SS deposited by LDED on AISI D2 substrate

Moyses Leite de Lima
Giovanna Fiocco Colombo
Jeferson T.
Marcelo Veiga

Palestra apresentada no BRAZILIAN MATERIALS RESEARCH SOCIETY MEETING, B-MRS MEETING, 21., 2023, Maceió. 23 slides

A série "Comunicação Técnica" compreende trabalhos elaborados por técnicos do IPT, apresentados em eventos, publicados em revistas especializadas ou quando seu conteúdo apresentar relevância pública. REPRODUÇÃO PORIBIDA

Instituto de Pesquisas Tecnológicas do Estado de São Paulo
S/A - IPT
Av. Prof. Almeida Prado, 532 | Cidade Universitária ou
Caixa Postal 0141 | CEP 01064-970
São Paulo | SP | Brasil | CEP 05508-901
Tel 11 3767 4374/4000 | Fax 11 3767-4099

www.ipt.br

FeB+C Ferramentarias Brasileiras Mais Competitivas

FERA
FERRAMENTAS MANUFATURADAS ADITIVAMENTE

Microstructure of a heat-treated 420S SS deposited by LDED on AISI D2 substrate

Moysés Leite de Lima[1]
Giovanna Fiocco Colombo[1]
Jeferson T. Pacheco [2]
Marcelo Veiga [2]

[1] Instituto de Pesquisas Tecnológicas,
[2] Instituto Senai de Inovação em Processamento a Laser,
e-mail: mllima@ipt.br

FERA - Ferramentas Manufaturadas Aditivamente: *Partners Network*

. Dr. Ronnie Rego
. Dr. Luís
zaga Trabasso
. Dr. h. c. Dr.-
Eckart Uhlman
Moysés Lima

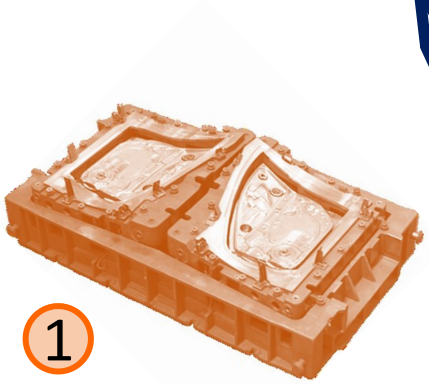
4 STI's

26 Companies

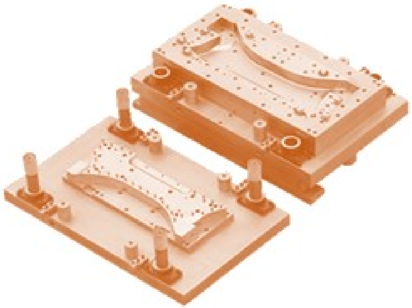
FERA - Ferramentas Manufaturadas Aditivamente

FERA

FERRAMENTAS
MANUFATURADAS
ADITIVAMENTE

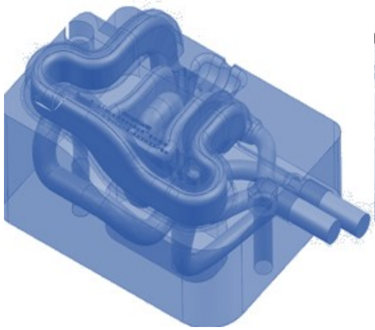


1 **Semi-automated AM Repair of stamping tools**

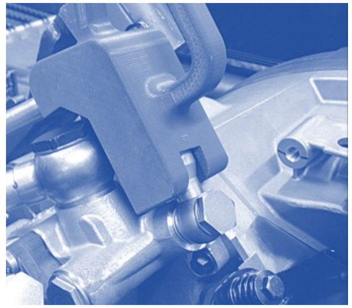


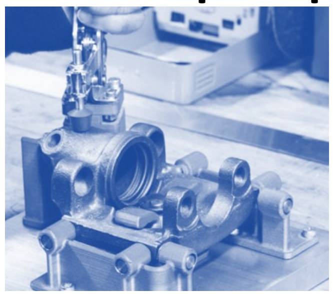
2 **AM of tools with complex**

es



3 **AM of fixtures/jigs and spare parts**





Motivation

- For a given material, the as-built resulting microstructures of AM processes are usually different from those obtained for the same material that undergoes the conventional processes.
- This is related to the AM process conditions, for example, high cooling rates, high solidification rates, high thermal gradient in the liquid, thermal cycles, and high residual stress (compared to the conventional processes).
- These conditions lead to a smaller length-scale microstructure, i.e., a more refined microstructure. For some materials, it takes place a change of the solidification morphology from an equiaxial-dendritic to columnar-cellular from conventional to AM processes.
- Moreover, the microstructures obtained with AM processes are usually far from equilibrium, which is related to the high solidification rates and thermal cycling.
- The refined (cellular spacing ~1µm) and out-of-equilibrium microstructure enforces a challenging for characterization. However, microstructure characterization is essential to understanding the AM processes, planning the post-processes steps, and establishing relationships with the mechanical properties.
- In the present work, the heat treatment definition is a challenge because the recommended conditions are different for the substrate (AISI D2)and the deposition (AISI 420).

Objectives

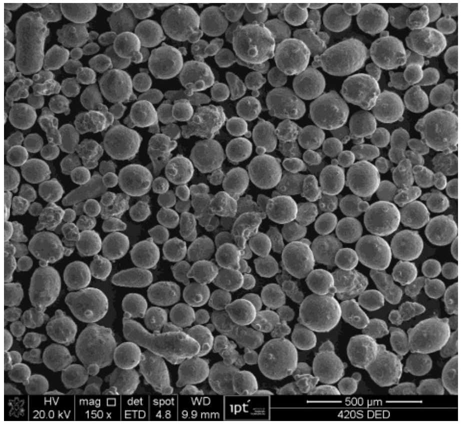
- Describe the AISI 420S steel microstructure deposited over a AISI D2 tool steel using DED-L in the as-built condition.

- Describe the effects of thermal heat treatment cycles in the AISI 420S steel microstructure.

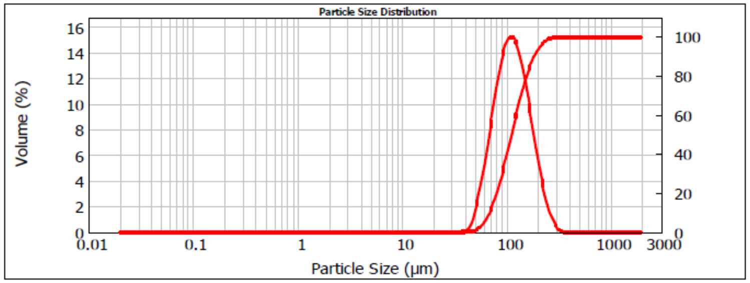
Materials and methods

AISI 420S Powder

SEM



Laser diffraction

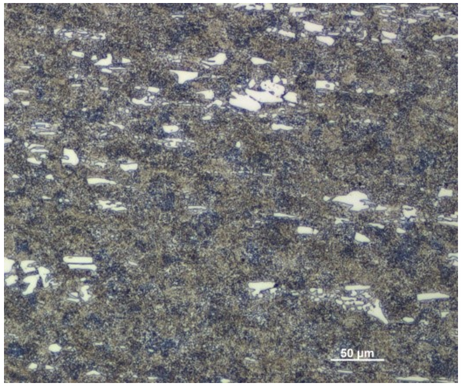


$D_{10} = 69\ \mu m$ $D_{50} = 112\ \mu m$ $D_{90} = 184\ \mu m$

Chemical composition – ICP-OES

Elements	*C*	*Cr*	*Mn*	*Si*	*Mo*
%wt	*0,22*	*13,6*	*1,34*	*0,5*	*0,275*

AISI D2 Substrate



Heat treatment:

- Pre-heating at 450°C;
- Pre-heating at 880°C;
- Austenitization at 1070°C;
- Marquenching until 520°C;
- First and second tempering at 530°C; Third tempering at 540°C.
- Hardness: 221,4 HV before heat treatment and ***640 HV*** after.

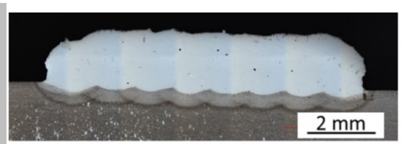
Chemical composition

Elements	*C*	*Cr*	*Mn*	*Si*	*Mo*	*V*
%wt	*1,55*	*12,00*	*0,35*	*0,30*	*0,75*	*0,90*

Materials and methods

Processes and samples preparation

DED-L processes parameters development



0.5

Layer height [mm]

Laser Power: 567 W
Scan speed: 700 mm / min
Hatch distance 1.1 mm
Feed rate: 8 g / min
Layer height: 0.5 mm

Samples cut by wire EDM

Conditions of studied samples

As-cladded sample

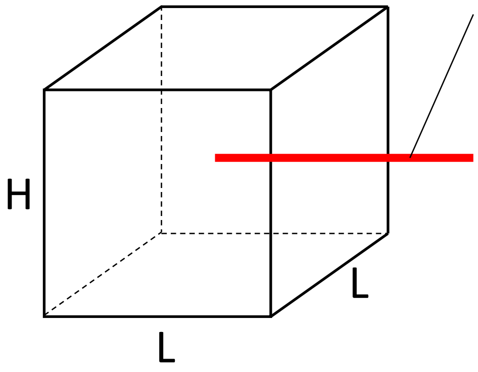
Austenitization at 1000 °C and quenched in air

Tempered at 300 °C, 400 °C and 500 °C (for 1h)

ITA · ipt Instituto de Pesquisas Tecnológicas · Instituto SENAI de Inovação Laser · Fraunhofer IPK Institute Production Systems and Design Technology · FUNDEP

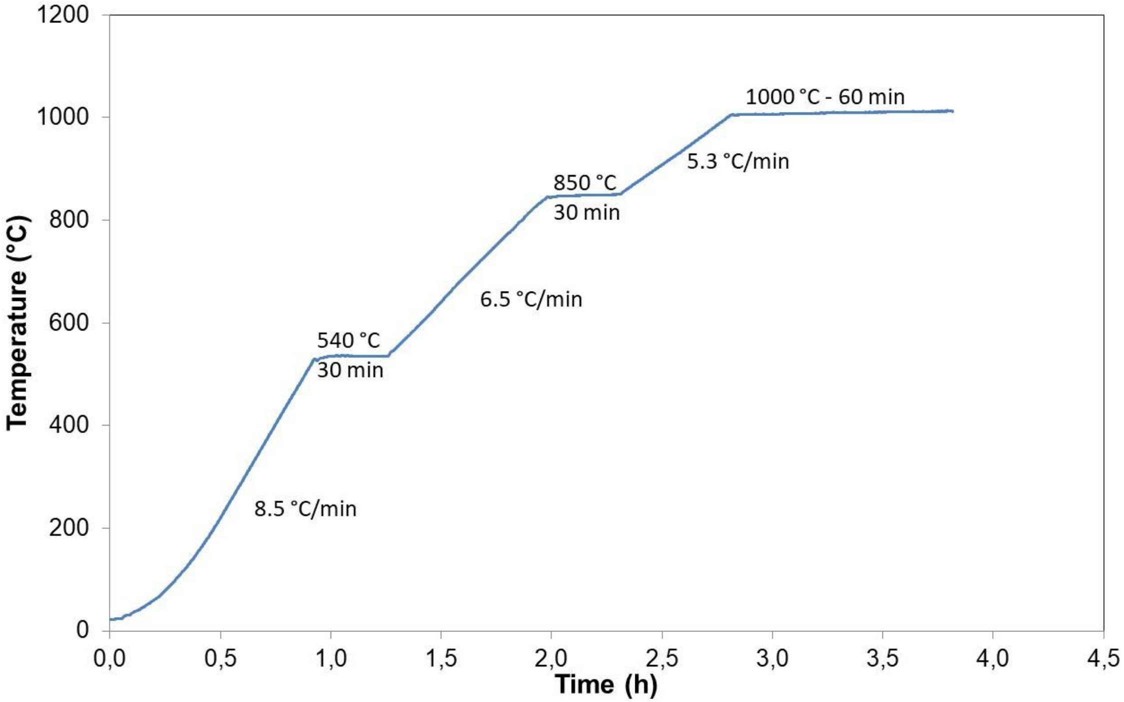
Materials and methods

Heat treatment



A hole was drilled up to the center to insert a thermocouple (type K)

H= 15 mm
L = 10 mm



Samples characterization

Characterization

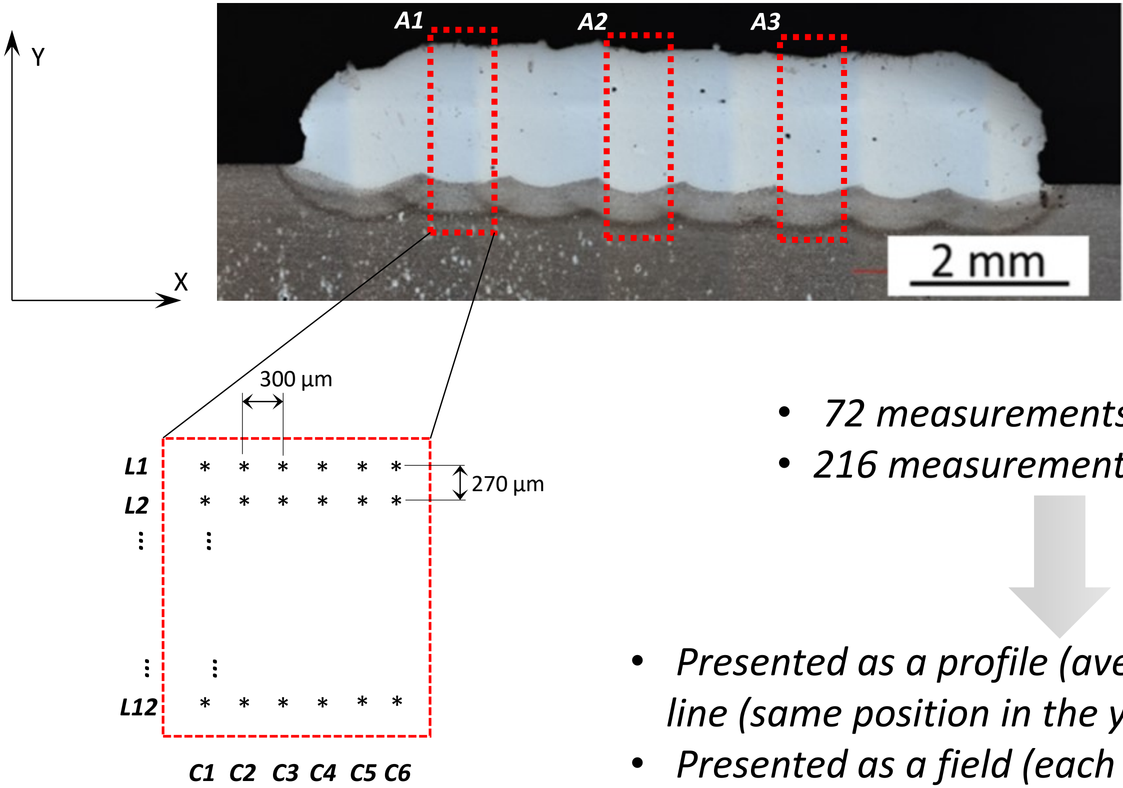
- Optical microscopy (OM) with samples etched with Vilella.
- Scanning electron microscopy (SEM) com EDS
- Microhardness Vickers (HV)

Modelling

- Thermocalc using equilibrium and Scheil solidification
- Carbon diffusion during the heat treatment using Dictra module on ThermoCalc

Materials and methods

Microhardness measurement



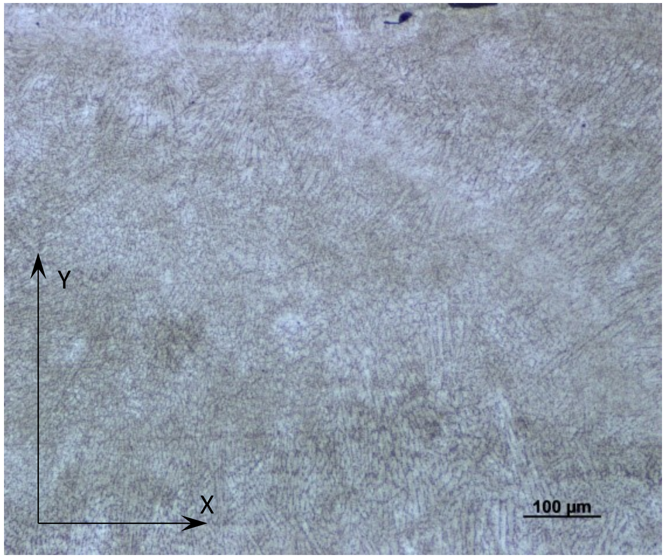
Position of microhardness measurements

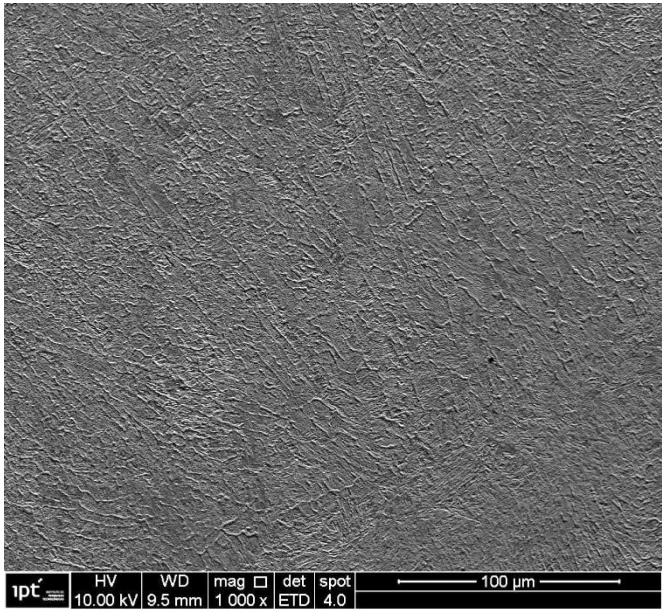
- *72 measurements per area*
- *216 measurements per sample*

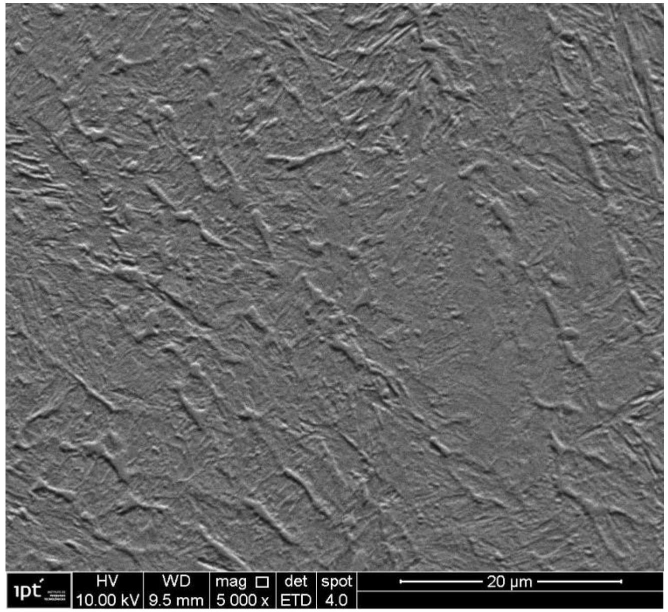
- *Presented as a profile (average of 18 in a same line (same position in the y direction)*
- *Presented as a field (each point is an average of 3 measurements at a same y position)*

Results and discussion – 420S deposition

As-built condition – OM and SEM



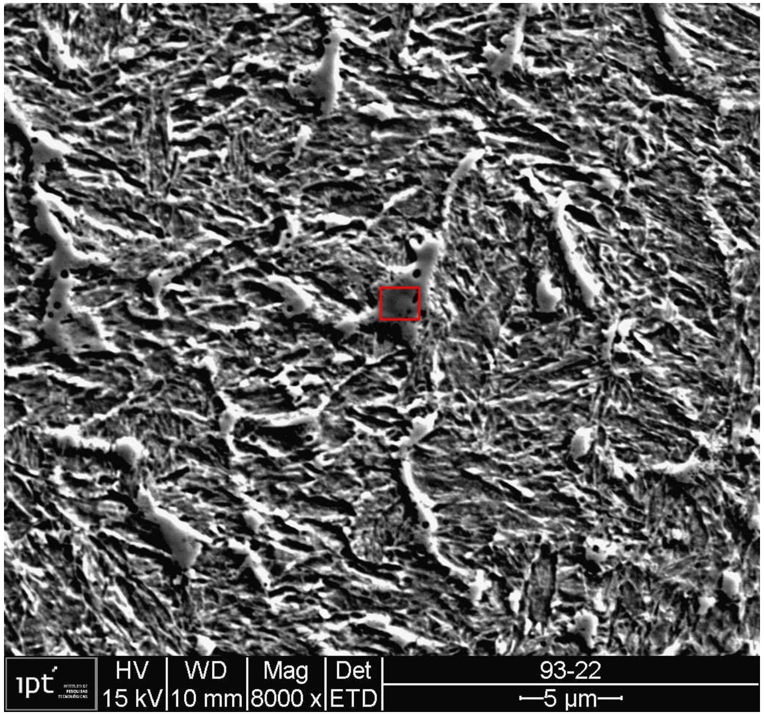




- It is possible to observe the solidification structure made up of dendrites and cells.
- In some regions it is possible to observe the direction of growth of cells/dendrites, forming a columnar structure, but not necessarily in the vertical direction.
- A columnar structure is expected in view of the cooling imposed on the deposited material by the substrate or previous deposition layers and the geometry of the weld pool.

Results and discussion – 420S deposition

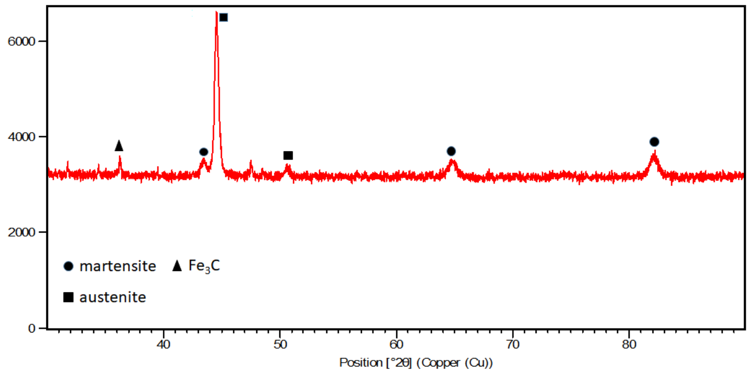
As-built condition – OM and SEM



EDS results of the indicated point

Element	Weight%	Atomic%
Si K	0.55	1.08
Cr K	18.28	19.26
Mn K	1.66	1.66
Fe K	79.50	78.00

In this image the regions in the center of cells / dendrites presents characteristics of martensite, while the region between the cells / dendrites could be retained austenite, which was detected by XRD. The EDS analysis results of indicate a solute concentration higher than the initial composition. This is a results of the expected microsegregation effect during solidification. The presence of martensite and retained austenite is according to the literature [1, 2, 3, 4].

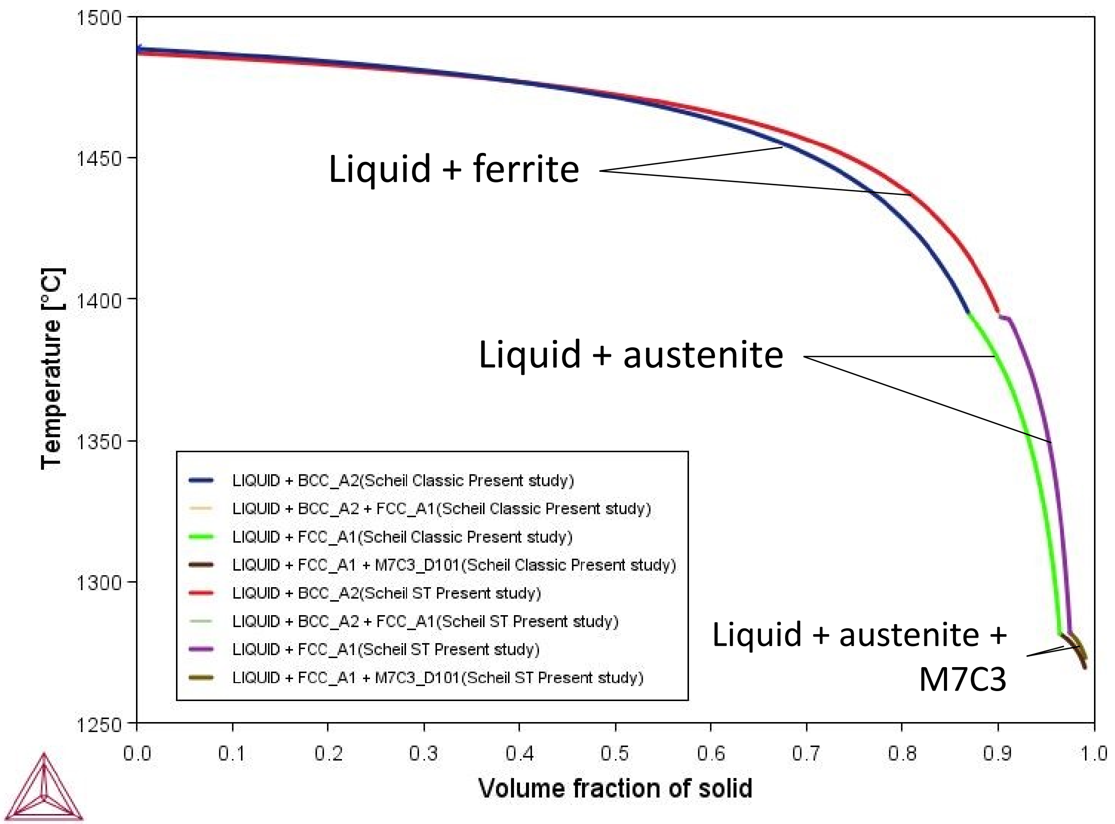


The XRD also indicate the formation of Fe3C. According to the literature [5], this carbide could be formed during the AISI 420 tempering.

[5] I A Channa et al., 2019, Effect of Tempering Temperature on the Properties of Martensitic Stainless Steel AISI-420

Modelling results

One of the results obtained with these models was the austenite chemical composition during the solidification considering that the microsegregation takes place according to the Scheil model. Using this chemical composition, the Ms temperature was estimated at -136 °C. This Ms temperature explained was the austenite between the cells/dendrites arms remains as retained austenite and did not transform to martensite. As a comparison, the Ms temperature for the nominal composition is around 210 °C.



Modelling results

Reference	Microstructure as-built condition	AM process	Chemical composition (wt%)						Eutectic fraction (%)	M7C3 fraction (%) using Scheil	
			Cr	C	Mn	Si	Mo	V		Classic	ST
Present study	Austenite + martensite	DED-L	13,60	0,22	1,34	0,50	0,28		3,7%	0,64%	0,38%
K Saiedi et al. 2019	Austenite + martensite	PBF-L	13,00	0,30	0,80	0,80			5,0%	0,95%	0,66%
Y Tai et al. 2021	Austenite + martensite	PBF-L	13,00	0,16	0,92	0,97			2,5%	0,34%	0,16%
G Ravi et al. 2013	Austenite + martensite	PBF-L	12,90	0,14	0,72	0,67			2,1%	0,25%	0,08%
X Zhao et al. 2015	Austenite + martensite + M7C3	PBF-L	13,90	0,36	0,73	0,28		0,32	6,6%	1,52%	1,08%

The microstructure of the as-cladded of AISIS 420 obtained in the present work is coherent with the literature: predominantly consists of martensite and retained austenite.

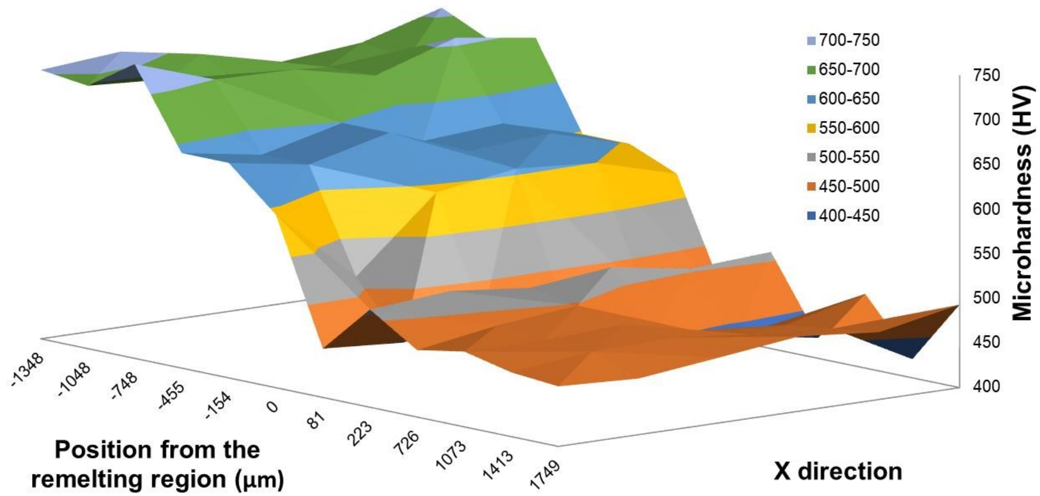
However, the simulations for microsegregation using Scheil models indicate the formation of an eutectic austenite + M7C3 at the end of the solidification.

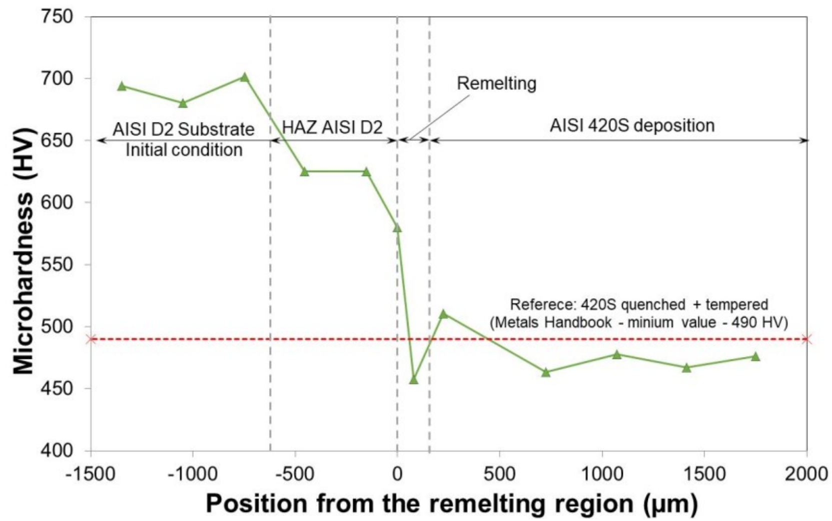
Using the condition of Scheil with solute trapping the eutectic fraction decreases with the increase of the scan speed (related to the solidification rate). Nevertheless, this model in ThermoCalc software considers the solute trapping only on the primary phase, decreasing the intensity of the solute trapping.

Moreover, the results found in literature for the AISI 420 steel processed by AM techniques shows that the chemical composition are not the same, although, for most of cases are within the standard range.

Results and discussion – 420S deposition

As-built condition – Microhardness

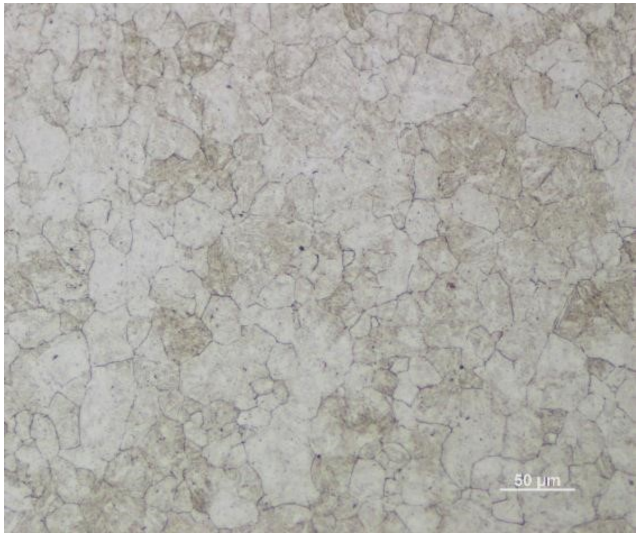




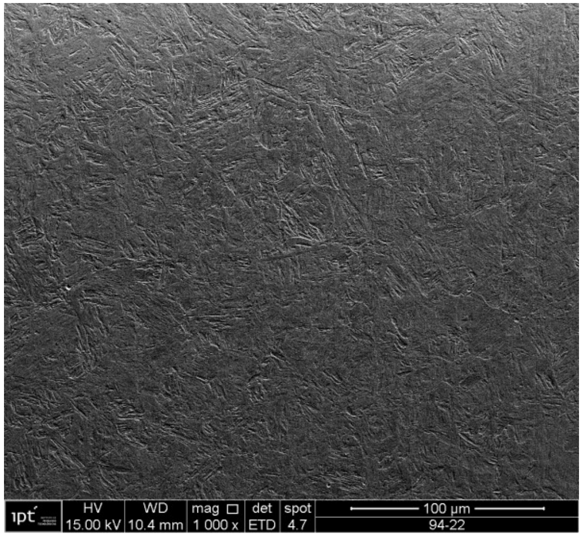
- The microhardness in the deposition region is irregular, which is related to the heterogeneous microstructure in the as-cladded condition.
- There is an abrupt decrease in the microhardness between the substrate and the AISI 420 deposition.
- In the substrate region, in addition to the HAZ, the remelting region presents a significant low microhardness result.
- The first point in the AISI 420 deposition presents higher microhardness compared to the other points in the deposition.

Results and discussion

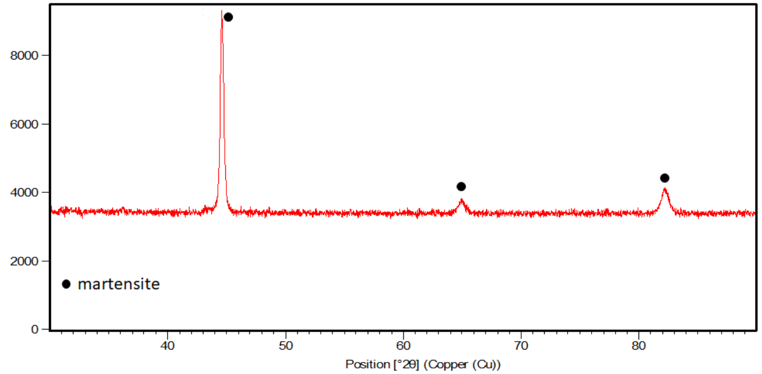
As-quenched condition – OM, SEM and XRD



OM



SEM

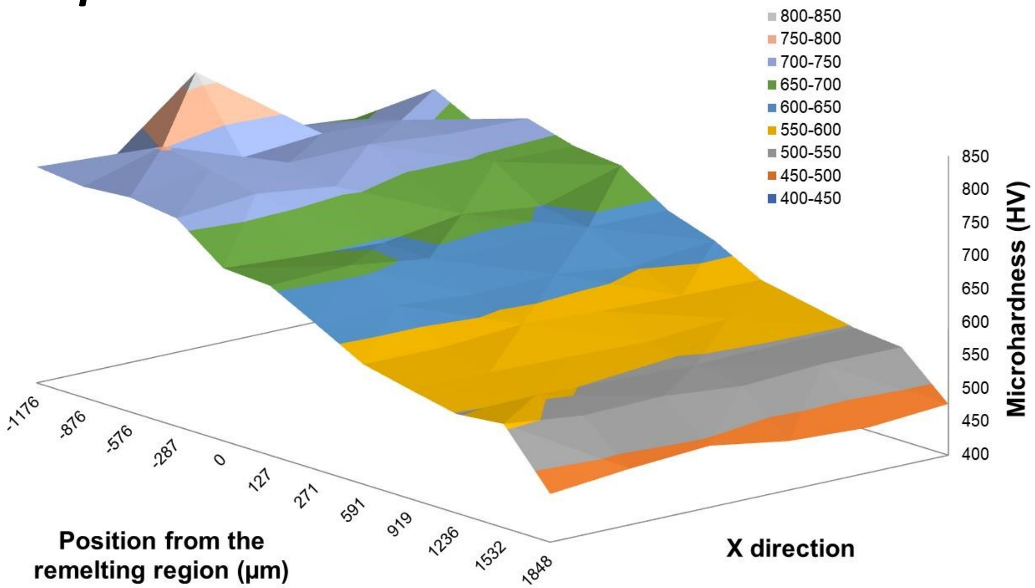


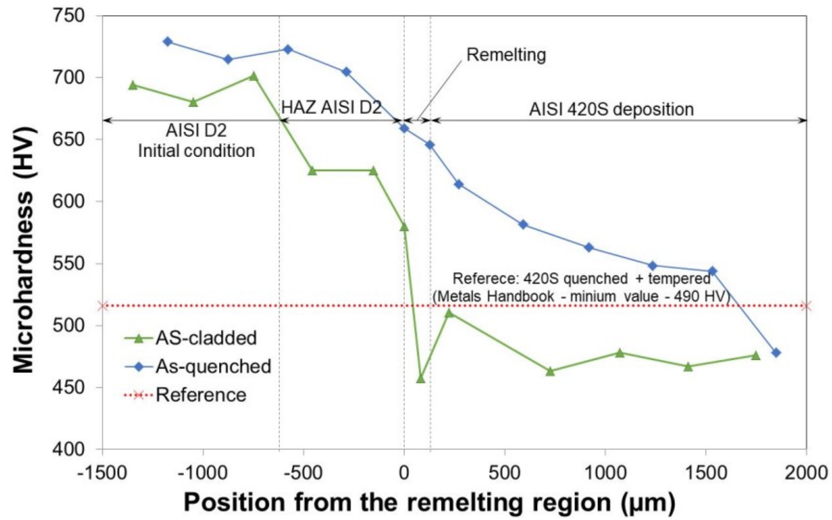
XRD

- In the as-cladded microstructure it was possible to observe the solidification structure indicating a columnar solidification. However, it was not possible to observe a clearly the grain structure. Moreover, it was possible to observe that there was regions with different phases.

- The microstructure in the as-quenched condition presents an equiaxed grain structure with an a predominantly phase. The XRD result indicated that this phase is martensite as expected for AISI 420

As-quenched condition – Microhardness

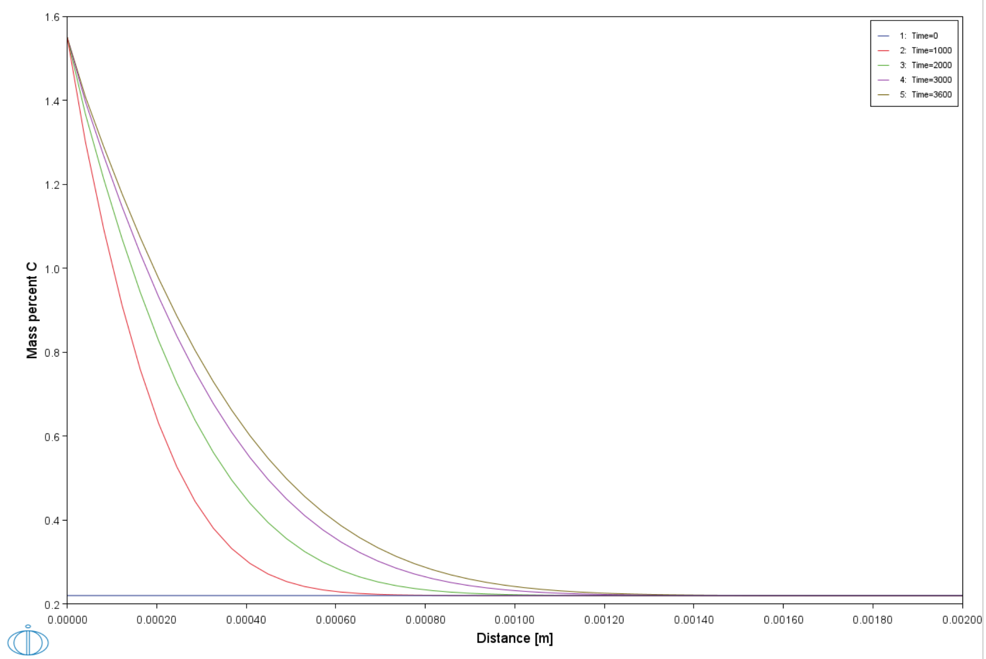


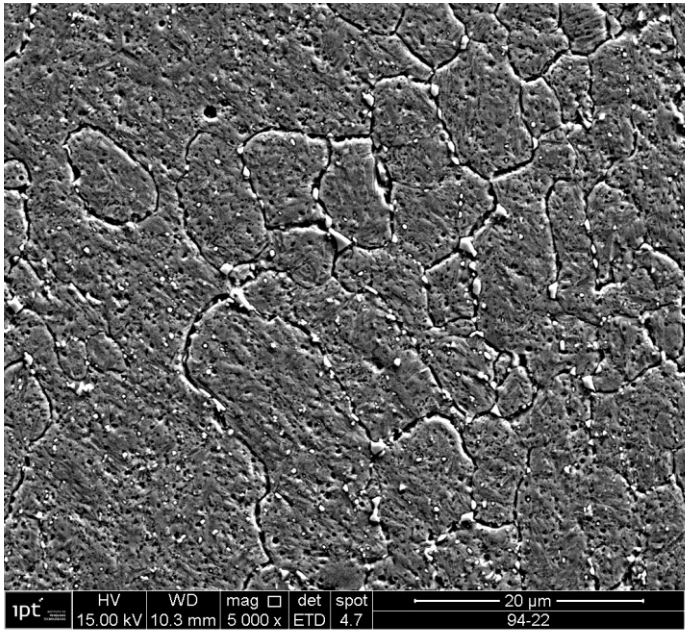


- The microhardness of the as-quenched condition presents a progressive decreasing from the substrate to the top of the deposition.
- In addition, the microhardness in the deposition became homogeneous at a given deposition height and presented an increase compared to the as-cladded condition.
- The HAZ and the melting region presented a significant increase in the microhardness compared to the as-cladded condition.
- The point at the top to of the deposition has a low microhardness compared to others, probably due to the carbon loss during the heat treatment.

Results and discussion

As-quenched condition – Modelling



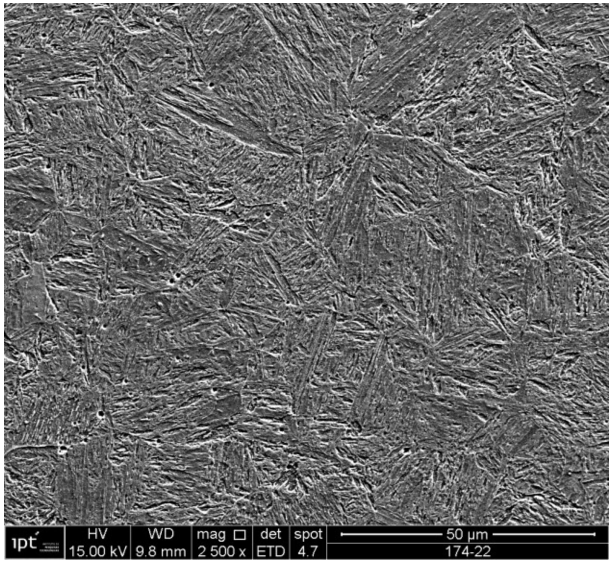


- The formation of the progressive decreasing of the microhardness from the substrate to the top of the deposition, the hypothesis of carbon diffusion during the austenitization step was evaluated using the diffusion modelling using ThermoCalc software.
- The results presented in graph above indicate that with the heat treatment conditions the carbon diffusion probably took place. This phenomenon increase the carbon content in the AISI 420 deposited and, then, its hardness.
- Another evidence of higher carbon content on AISI 420 near the D2 is the presence of carbides precipitated in this region after the quenching.

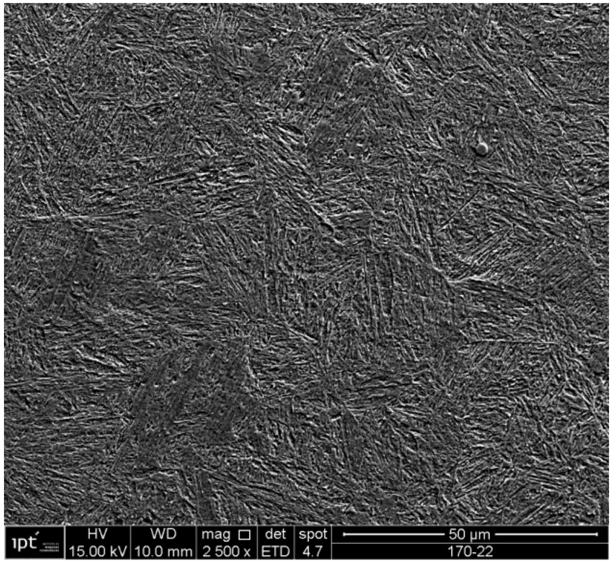
Results and discussion

Quenched + tempering condition – SEM

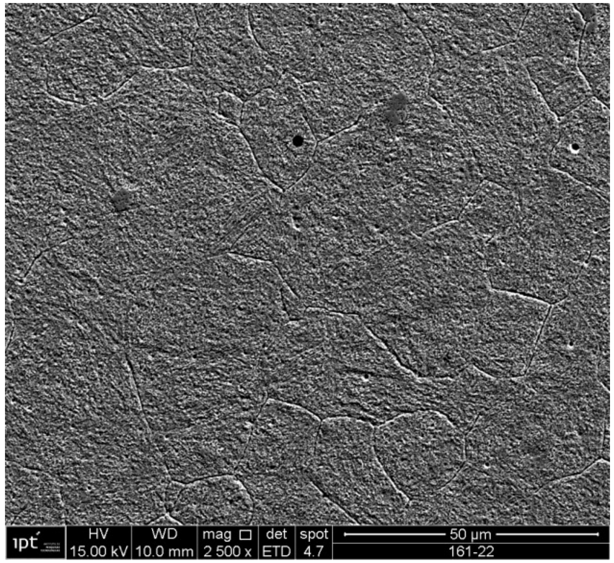
Quenched + tempering at 300 °C



Quenched + tempering at 400 °C



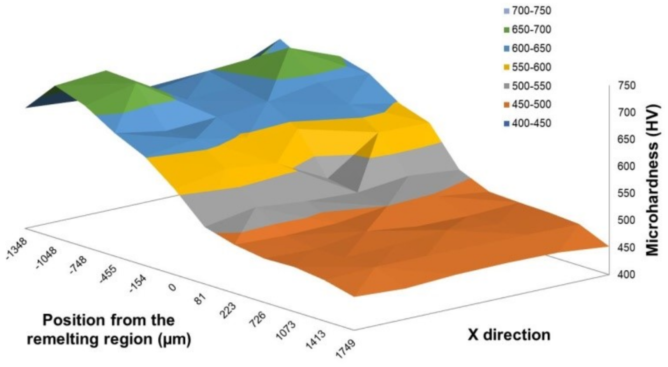
Quenched + tempering at 500 °C



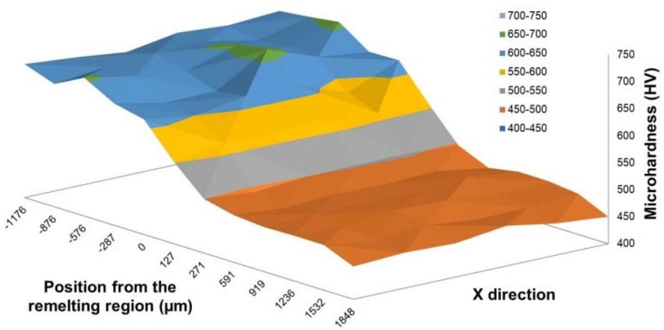
The SEM indicated that tempering at 300 °C and 400 °C did not lead to a significant change in the microstructure, while the tempering at 500 °C clearly shows the modification of the martensite.

Results and discussion

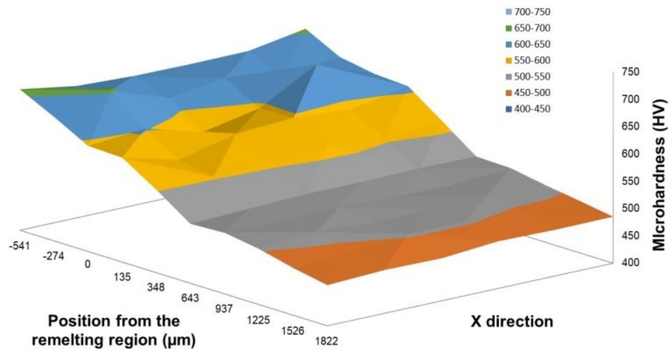
Quenched + tempering condition – Microhardness



Quenched + tempering at 300 °C



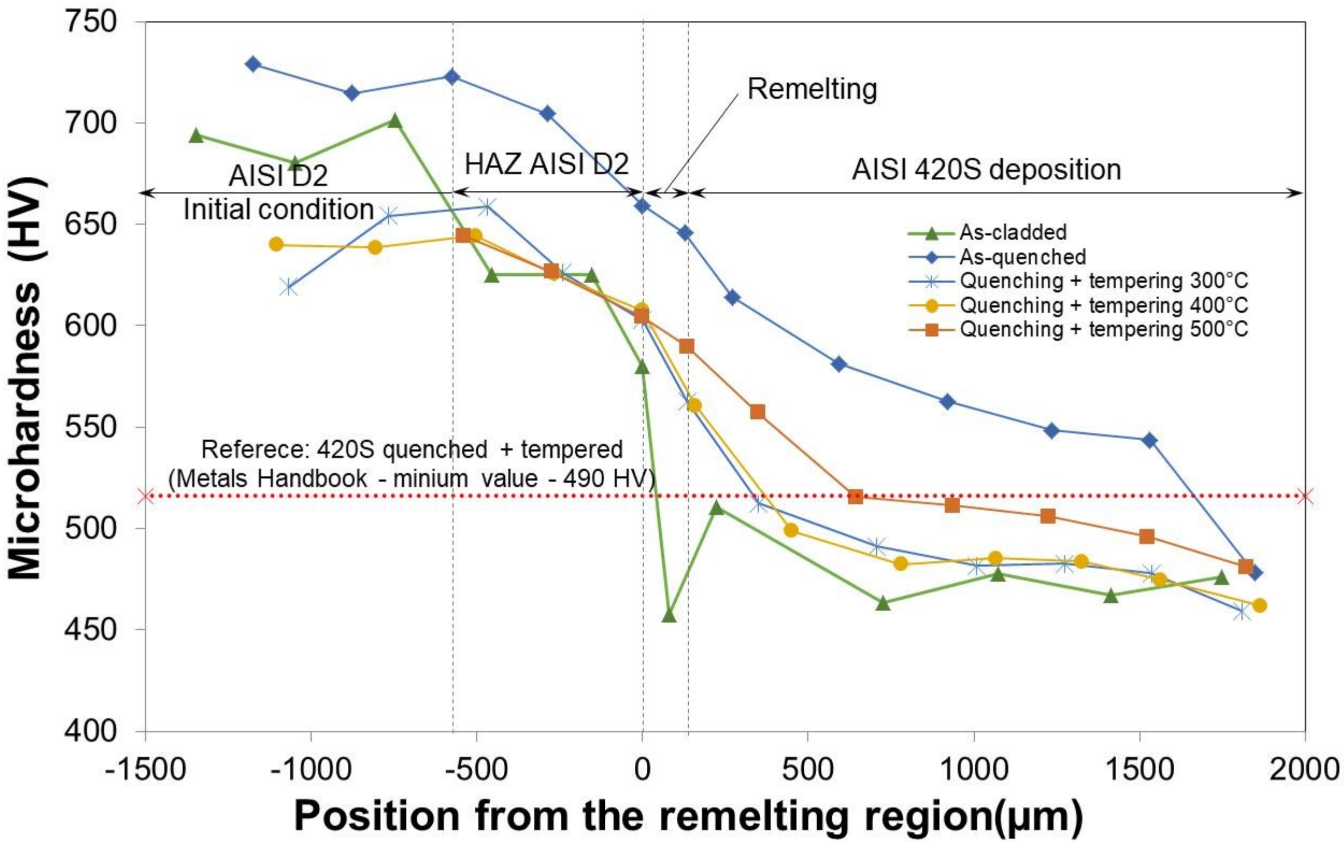
Quenched + tempering at 400 °C



Quenched + tempering at 500 °C

Results and discussion

Quenched + tempering condition – Microhardness



Conclusions

- ***The solute trapping effect must be considered for the analysis of the as-built condition microstructure for materials processed by AM techniques.***

- ***The deposit of AISI 420 steel on AISI D2 tool steel resulted in an abrupt drop in hardness at the interface between the materials in as-built condition (remelting region and the thermally affected zone). Furthermore, the microhardness profile indicates an abrupt drop from the substrate to the material deposited in the as-built condition.***

- ***The microhardness results showed microstructural heterogeneities of the deposited 420S stee in the as-built condition.***

- ***The quenching heat treatment resulted in a microhardness profile with a progressive decrease from the substrate to the deposited material. This microhardness profile after quenching is possibly a result of the transport of carbon by diffusion from the substrate to the material deposited in the austenitization step.***

- ***There was a possible recrystallization of the material deposited during the austenitization step.***

- ***Tempering at 500 °C after quenching resulted in an increase in microhardness when compared to tempering at 300 °C and 400 °C, which are similar to each other.***

- ***Comparison of the results of the present work with data found in the literature indicates that variations in chemical composition within the limits established for 420 steel can result in significant variations in the as-built AISI 420 microstructures when processed by AM techniques.***

Obrigado!

Thank you!

Ronnie Rego, Prof. Dr.

Luís Gonzaga Trabasso, Prof. Dr.

Eckart Uhlman, Prof. Dr. h. c. Dr.-Ing.

Moysés Leite de Lima, Me.