Effect of Heat Treatment on Microstructure and Microhardness of a C-Mn Steel / Inconel 625 Coating System

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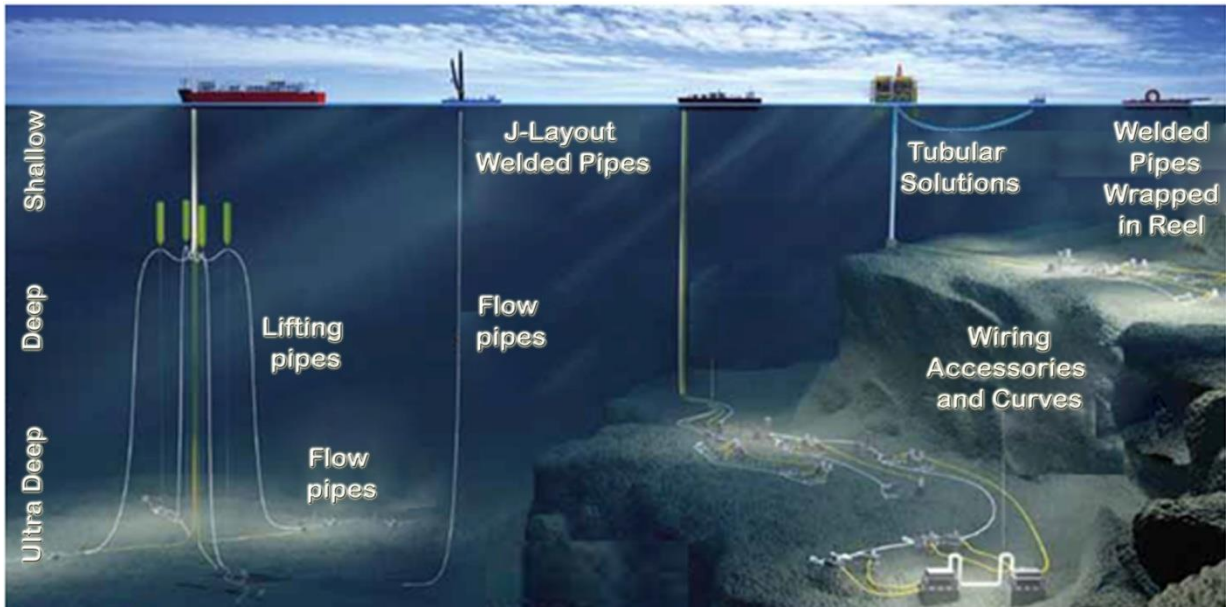
Content

- Motivation and Introduction
- Materials and Methods
- Results and Discussion
- Conclusions

Motivation and Introduction

The main motivation is: Material development for the **OIL & GAS** industry



Source: http://vallourec.com

The Main Challenges are:

(1) High-strength material for deep water application — Which request: Fatigue resistance, collapse resistance, internal pressure resistance

(2) Corrosion resistance: e.g., H_2S/CO_2

Motivation and Introduction

Common material used in the oil& gas industry today: Low C-Mn Steels

Positive aspects:
- Low cost;
- Easy manufacturing;
- High-strength due to special alloying.

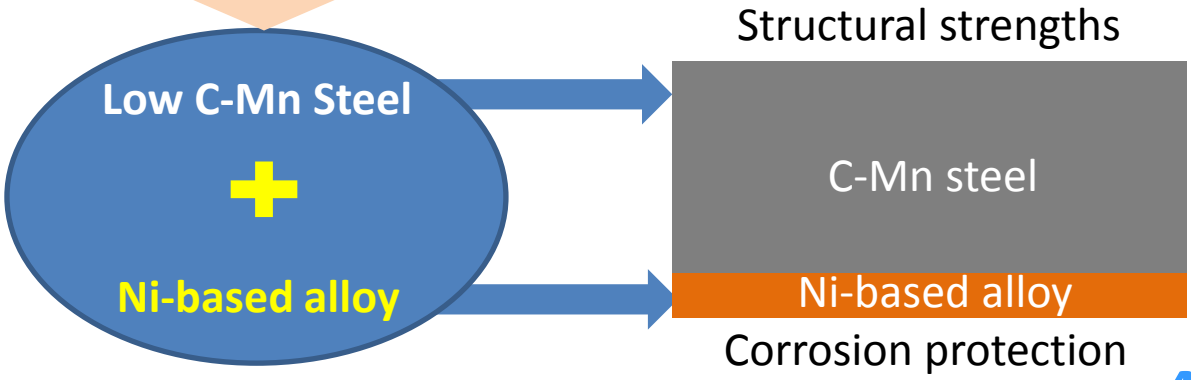
Negative aspects:
- Low corrosion resistance for aggressive environment.

Noble material candidate for the oil& gas industry: Ni-Based Alloys

Positive aspects:
- High corrosion resistance for aggressive environment;
- High-strength material.

Negative aspects:
- High cost.

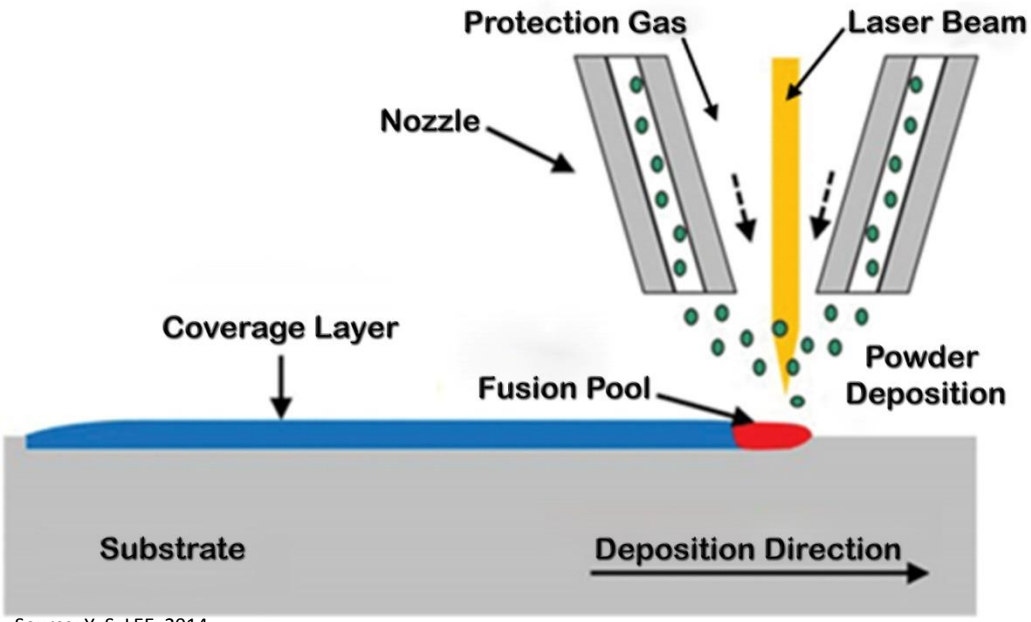
Hybrid Solution:



Specific Targets of this Project

1. Characterization of the C-Mn steel API 5CT L80.
2. Characterization of C-Mn steel/Inconel 625 after laser welding Coating.
3. Evaluation of different heat treatments of the C-Mn steel/Inconel 625 hybrid system.

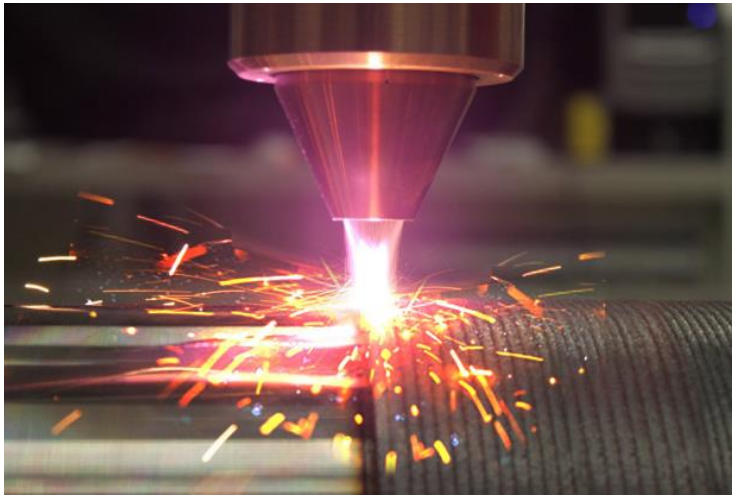
The Deposition Method of Inconel on C-Mn Steel Surface was Laser Welding Coating



Source: Y. S. LEE, 2014.

Because

It is a high-energy process avoiding large Heat Affected Zone (HAZ) in the steel substrate.

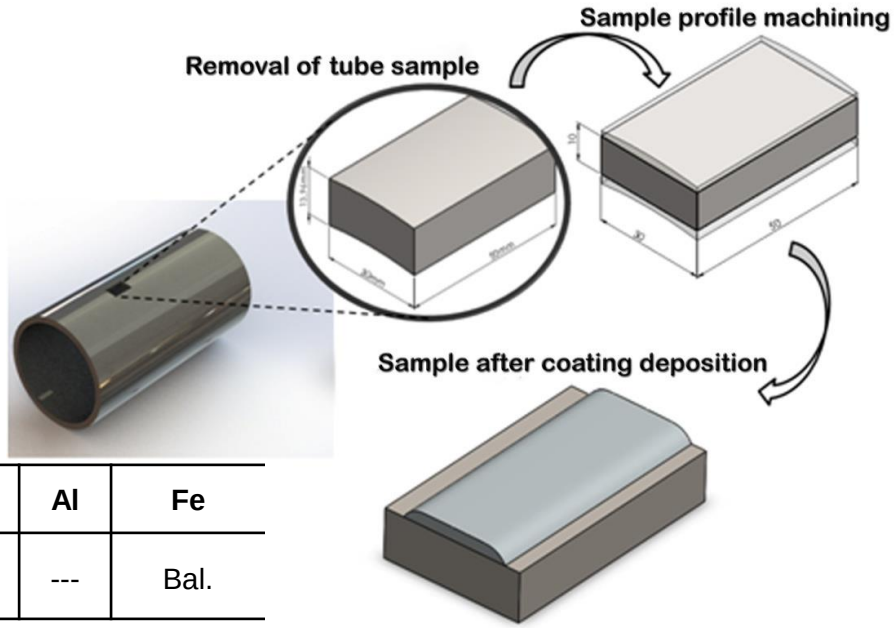


Source: LOUKAS WELDINGS, 2016.

Materials and Methods

Steel Used

Seamless pipe from C-Mn steel according to the standard API5CT Grade L80 Type 1.



Specified chemical composition [wt.%].

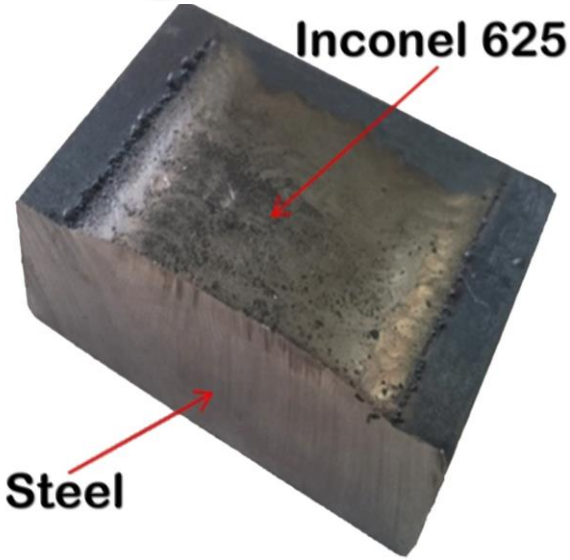
C	Mn	Si	Cr	Ni	Mo	Ti	Cu	B	Al	Fe
0.43	1,90	0,450	---	0,25	---	---	0,350	---	---	Bal.

Coating material

INCONEL® 625

Specified chemical composition [wt.%].

Ni	Cr	Mo	Nb	Al	Ti	Fe	Mn	Si	Co	C
58,0	22,0	9,0	3,6	0,4	0,4	2,5	0,5	0,5	1,0	0,1



The Microstructural Analysis was done using Scaning Electron Microscopy - SEM:

Three different chemical solutions were used.

(1) Etching solution for the *steel substrate*: Nital 2%

(2) Etching solution for *prior austenite grain size* of the steel within the HAZ caused by laser welding Coating: Teepol

(3) Etching solution *microstructure* analysis of the *Inconel 625* welded Coating: Tri-acid

Etching solution	Composition
Nital 2%	2ml of nitric acid + 98ml of etilic alcohol
Teepol	50ml of ether + 80ml water + 2 drops of HCl + 3g of picric acid
Tri-acid	Hypochoridirc acid + nitric acid + acetic acid: concentration: 1:1:1.

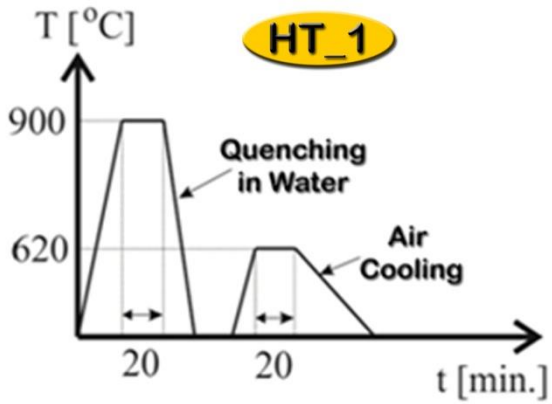
Heat Treatment Routes

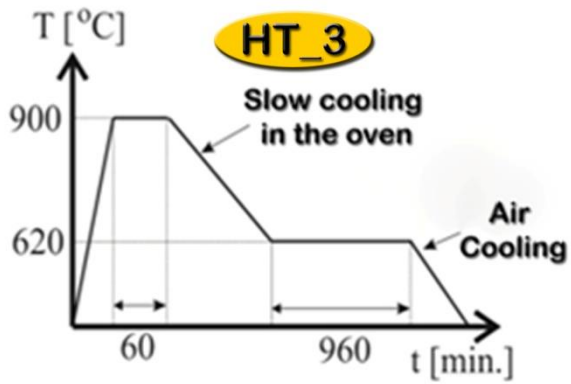
It was used 5 heat treatment conditions

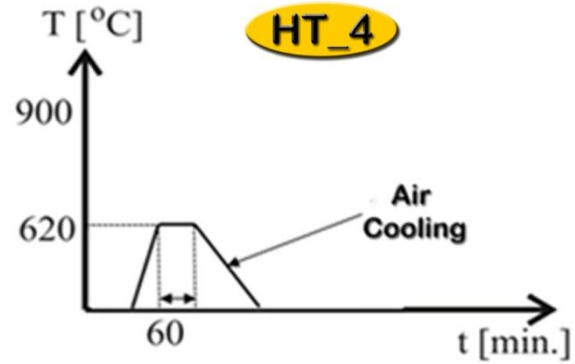
Two Quenching&Tempering with different soaking times.

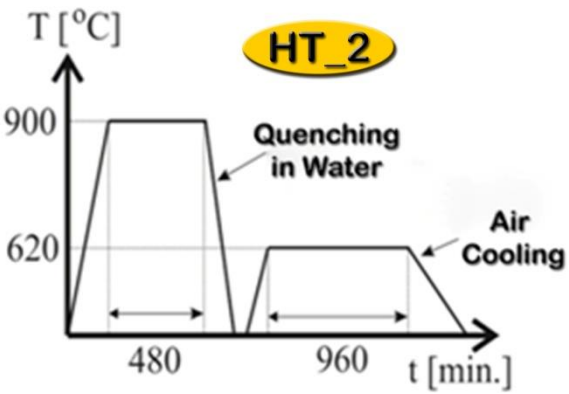
One austenitizing followed by slow colling

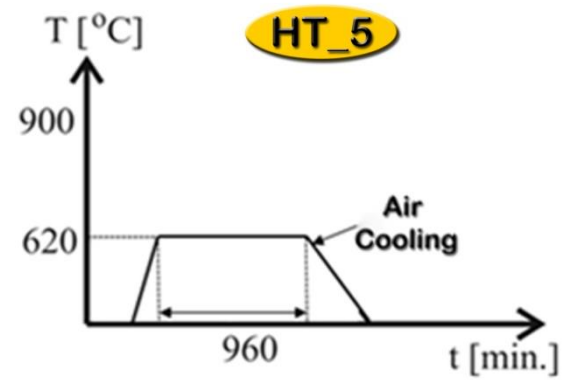
Two tempering with different soaking times.











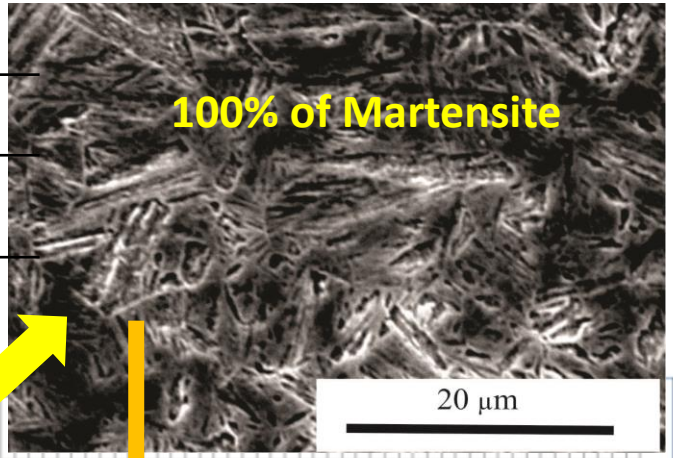
Characterization of the steel pipe used

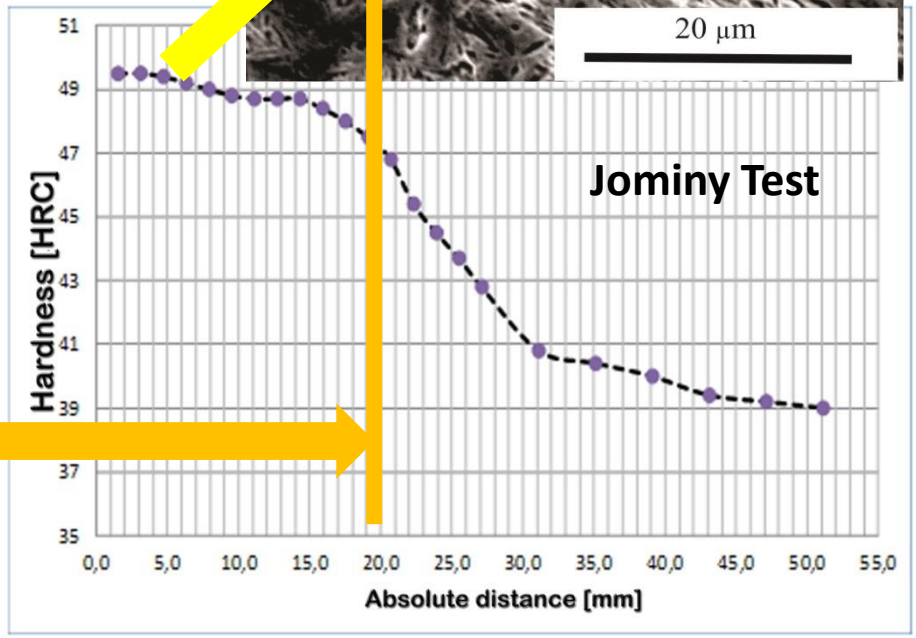
Chemical composition [wt. %]

C	Mn	Si	Cr	Ni	Mo	Ti	Cu	B	Al	Fe
0.26	1.0	0.15	0.30	0.02	0.03	0.04	0.06	0.0015	0.03	Bal.

Medium C-Mn steel

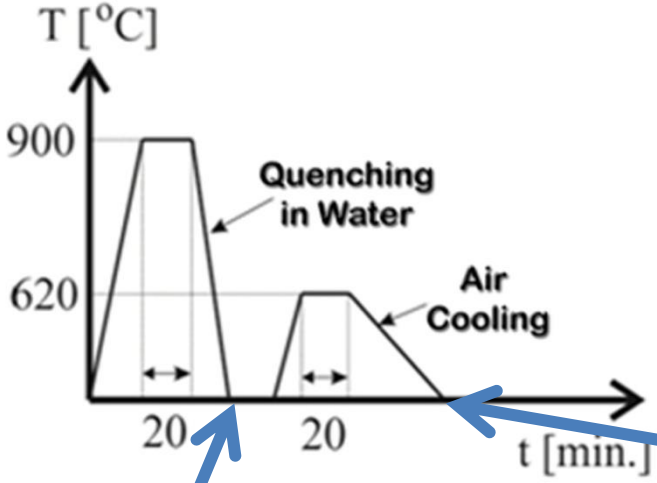
Intentionally added to enhance hardenability



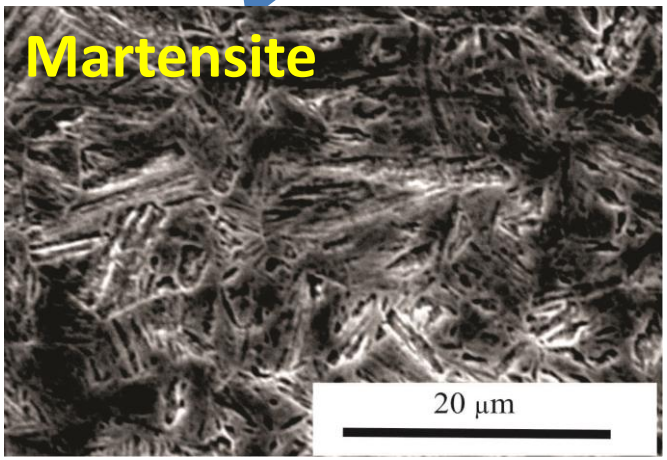


The excellent hardenability can be shown in the Jominy test forming 100% of Martensite

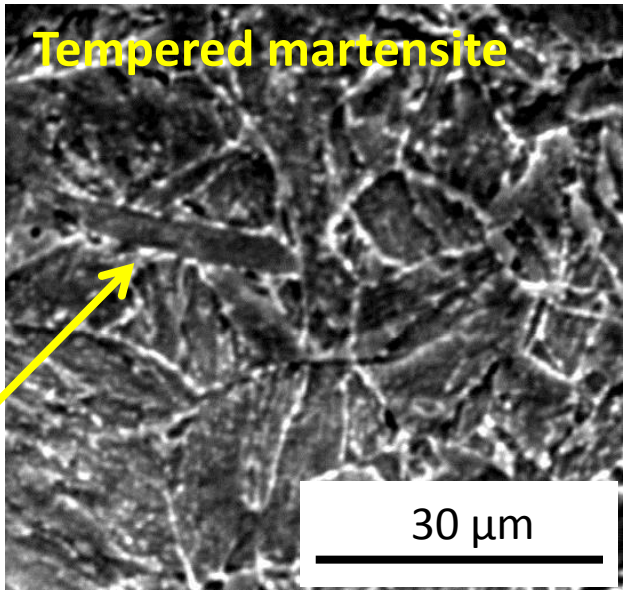
Heat treatment of Quench & Tempering of the Steel Pipe



Mechanical properties	Results
Yield strength	624 MPa
Ultimate tensile strength	720 MPa
Hardness	230 HV1



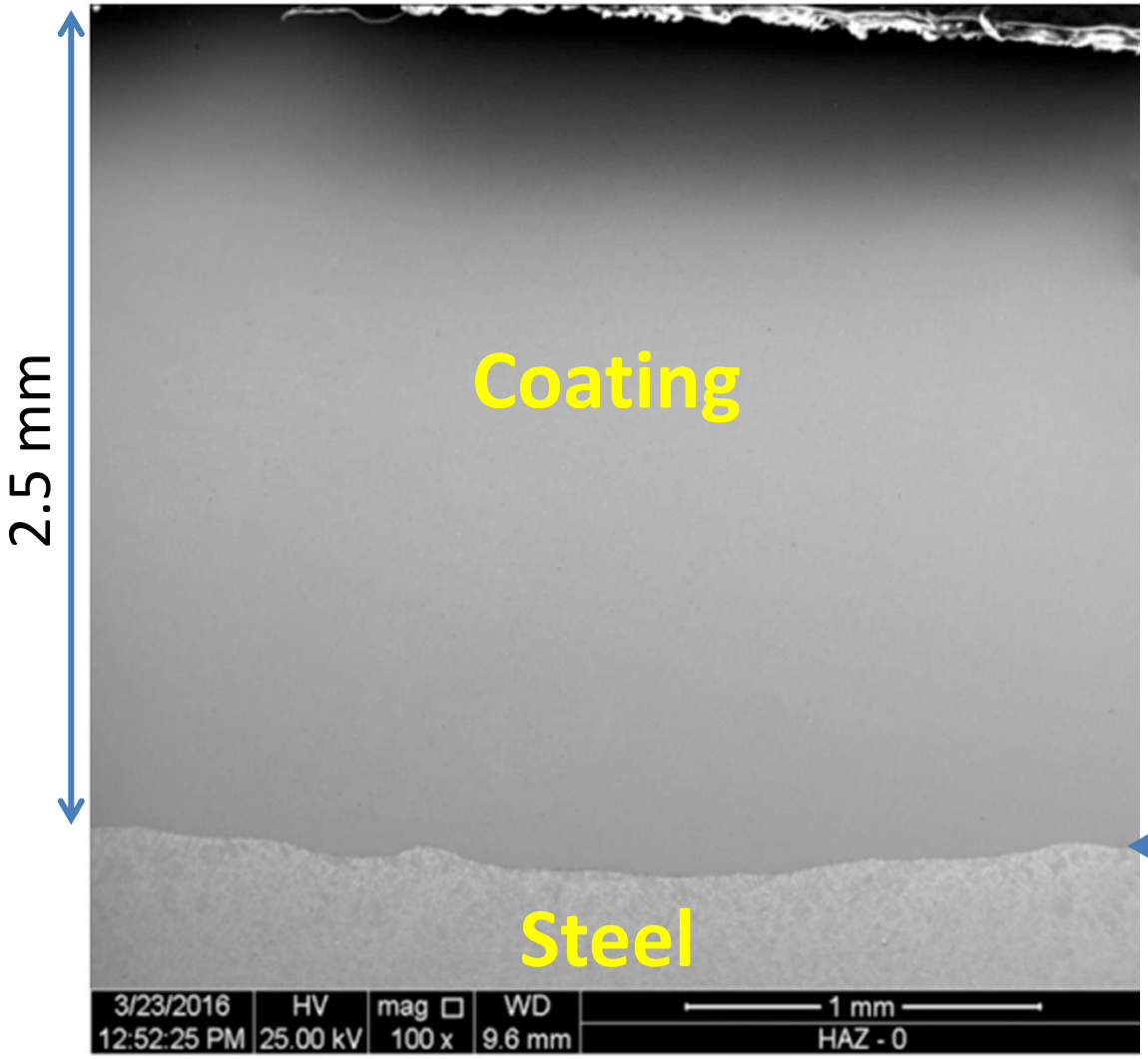
carbide precipitation "white spots"



Results and Discussion

As-Deposited: Steel + Coating

Steel / Inconel 625 Coating (macrograph)



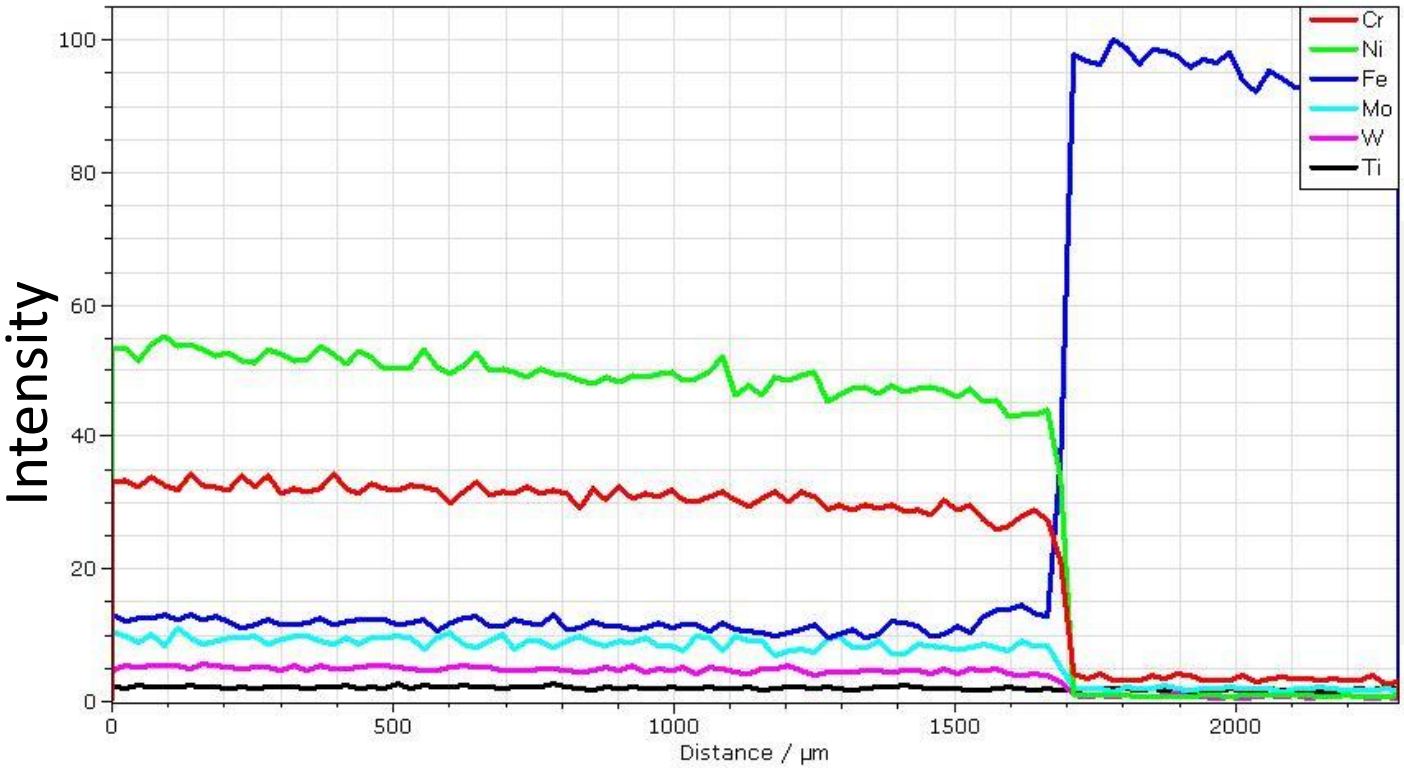
The quality of deposition was good .
Absence of porosity/voids within the coating

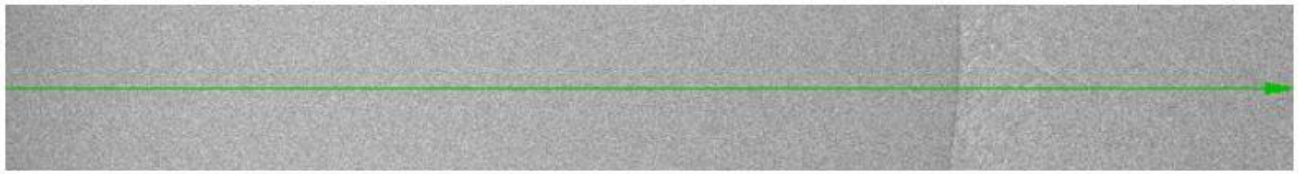
No defect in the steel/coating Interface was observed

Results and Discussion

As-Deposited: Steel + Coating

EDS measurement





Inconel 625 Coating **C-Mn steel**

The main elements are Fe in the steel.

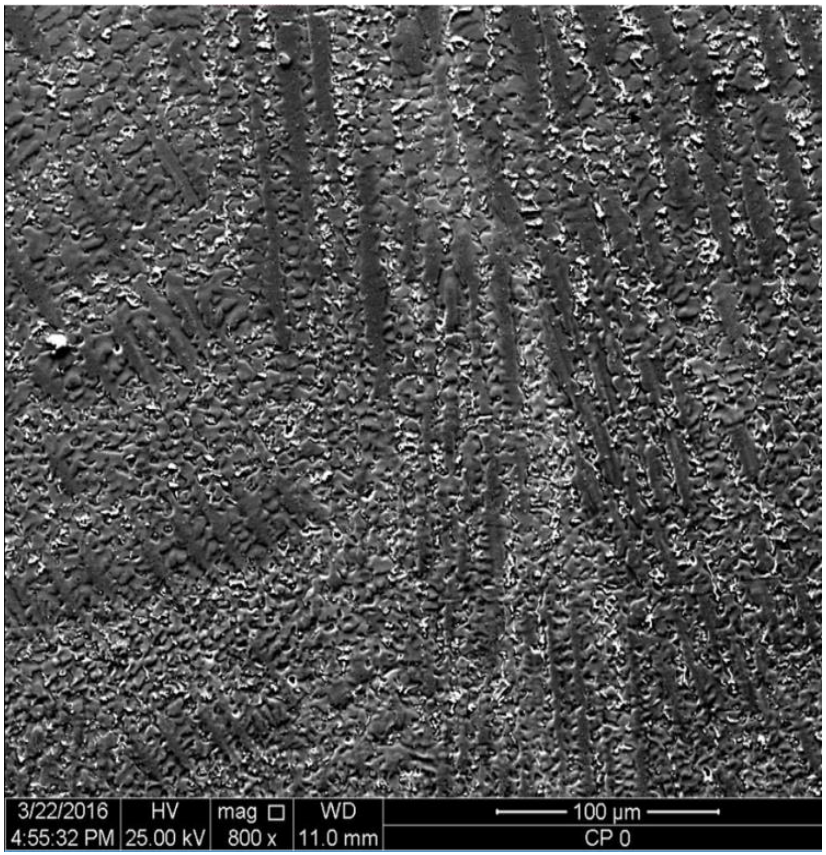
Ni and Cr in the coating region.

Results and Discussion

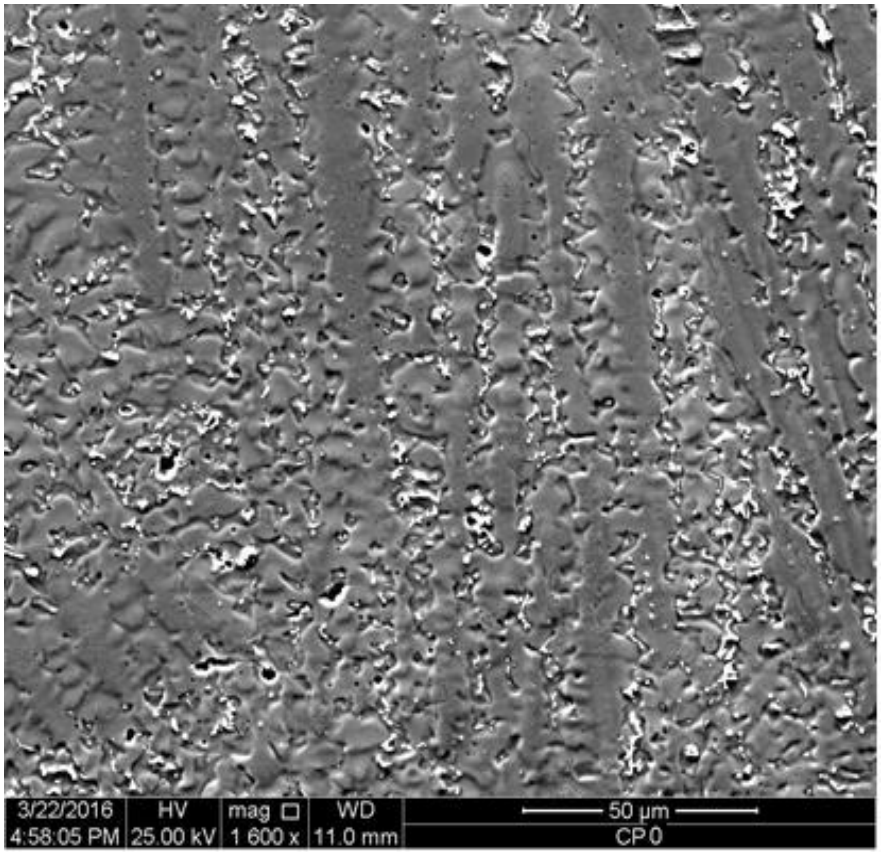
As-Deposited: Steel + Coating

Inconel 625 Coating

It is formed Columnar dendrites in the direction of heat extraction

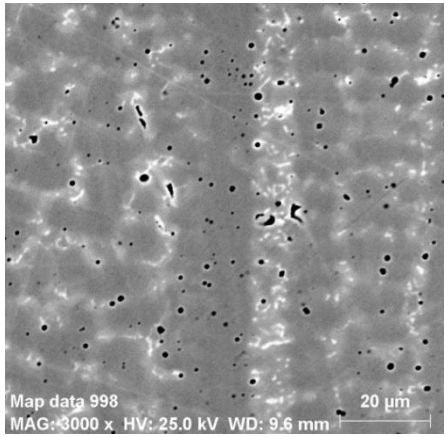


Magnification 800 X

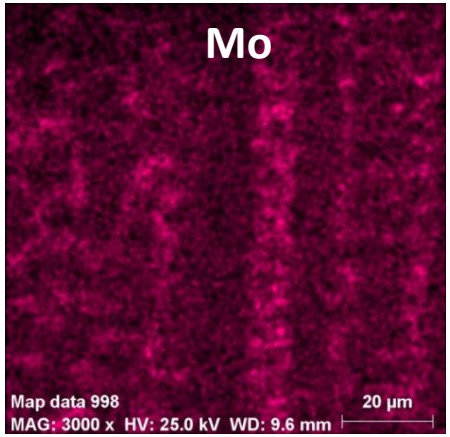


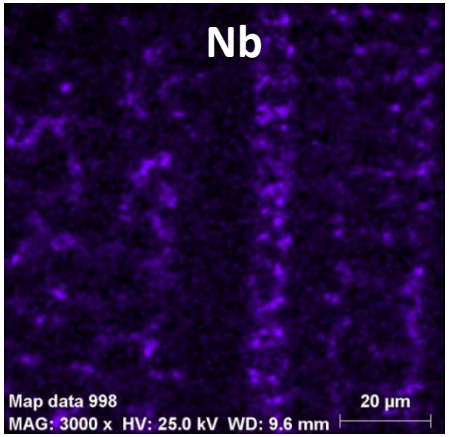
Magnification:1600 X

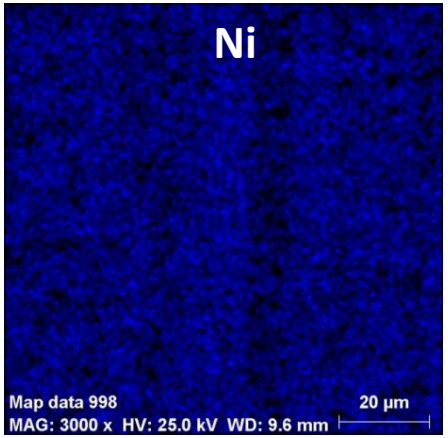
EDS mapping of Inconel 625 Coating

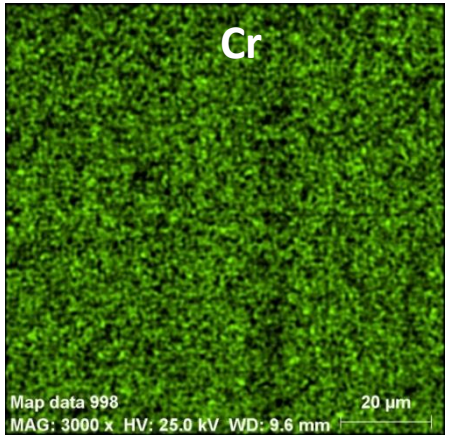


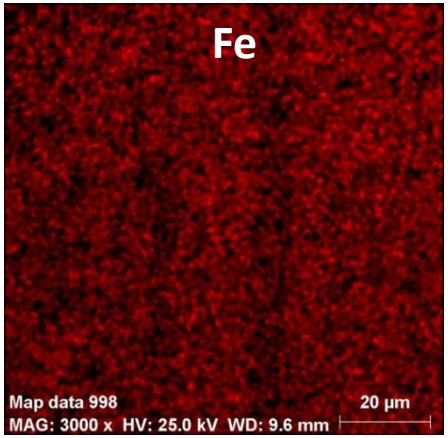
SEM: 3000X







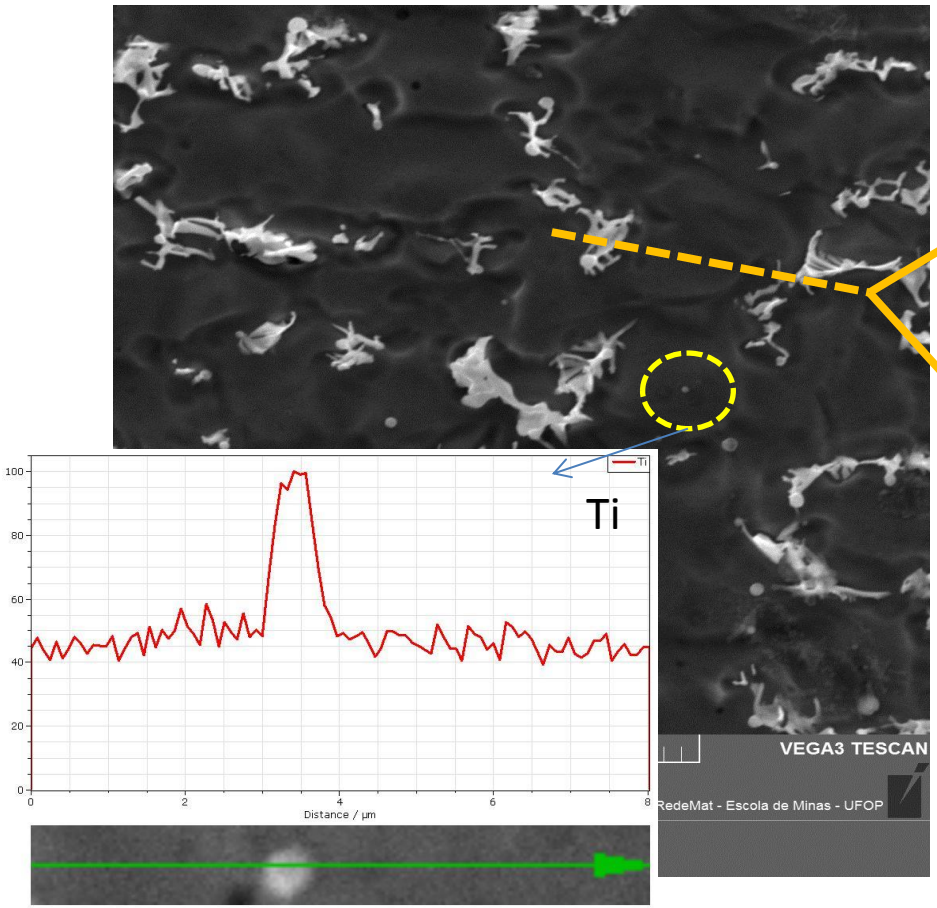


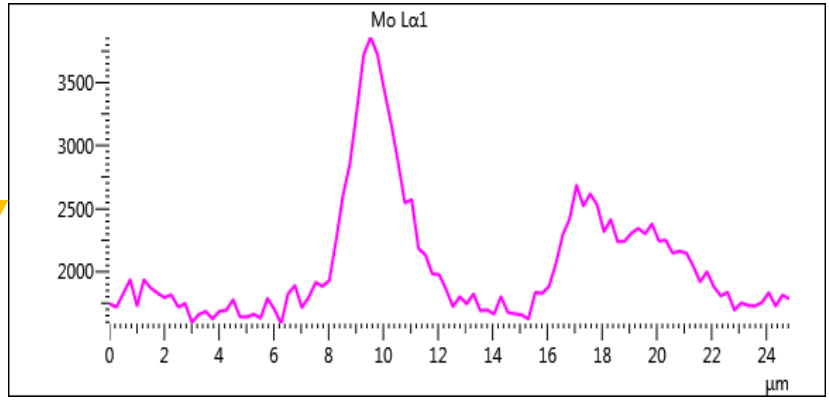


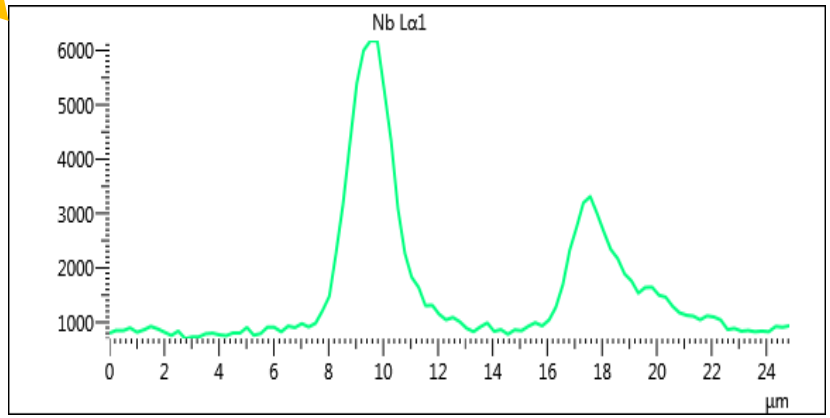
Showing that the white phase are Mo and Nb carbides.

EDS lineScan of Inconel 625 Coating

"Massive" presence of Mo and Nb carbides.
"Fine" Ti carbide was also observed.





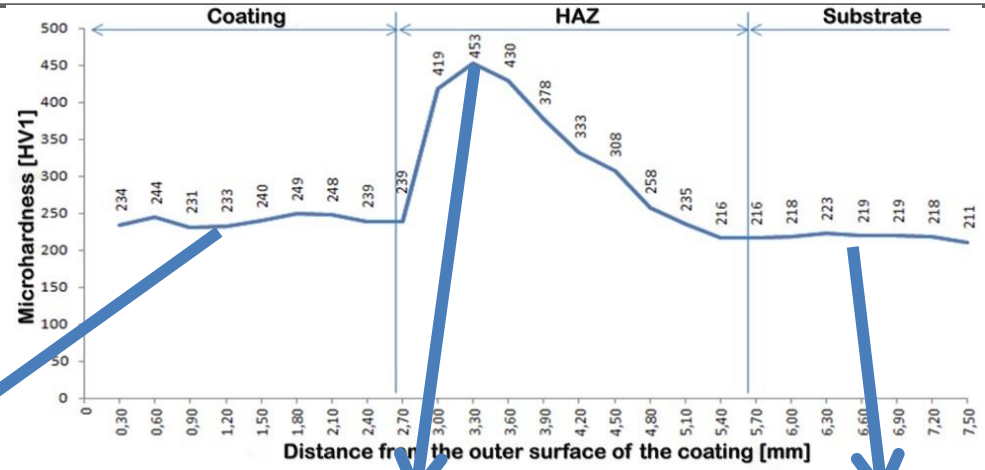


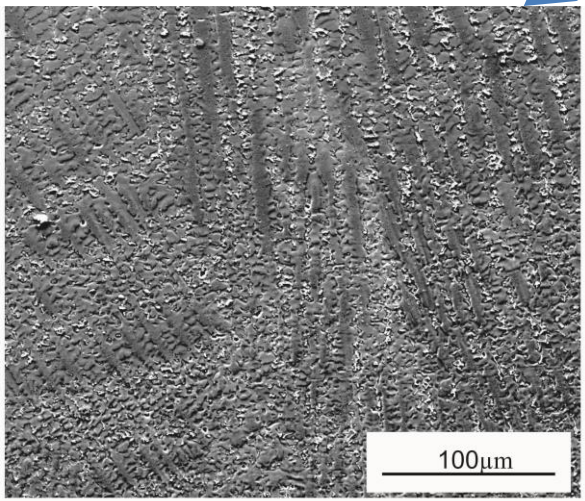
Results and Discussion

As-Deposited: Steel + Coating

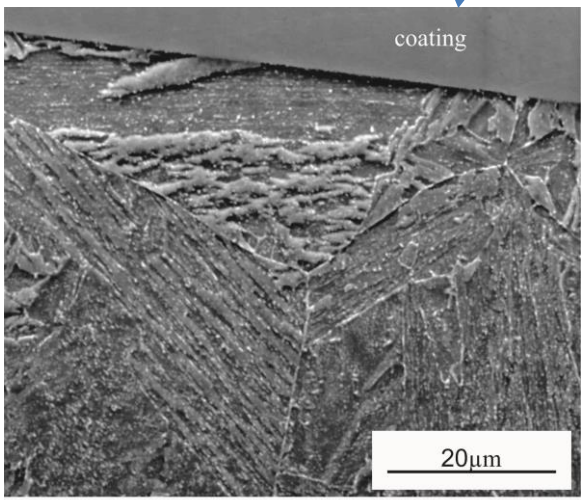
The profile shows three regions with different hardness values.

- The coating hardness: 230HV1
- The maximum HAZ hardness: 453HV1
- The steel average: 220HV1.



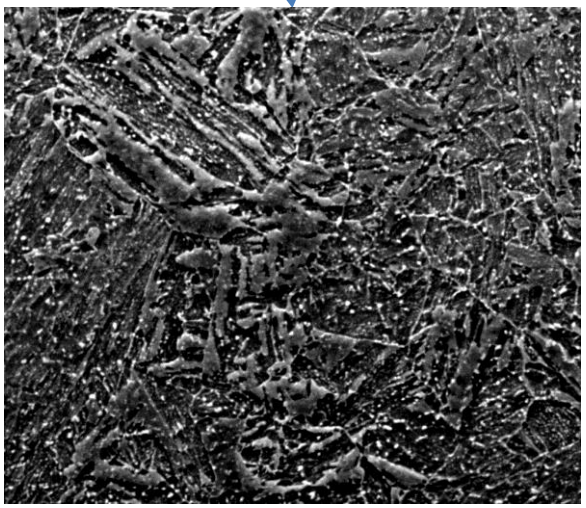


As-deposited Coating



Bainite

Is formed in the HAZ caused by the heat input of the laser welding and rapid cooling.

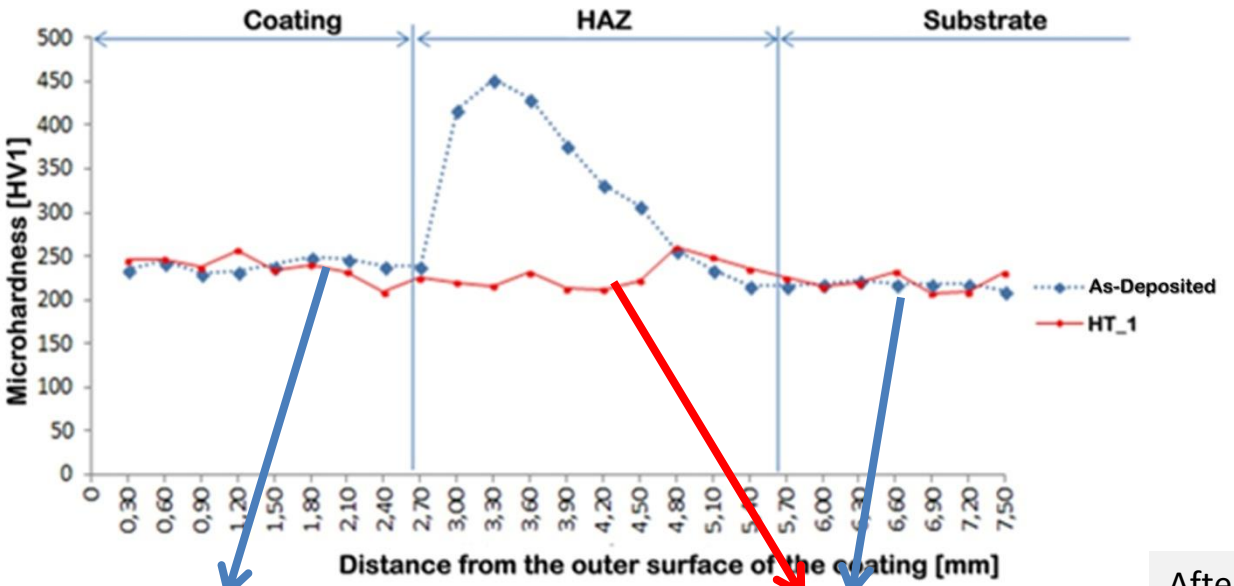


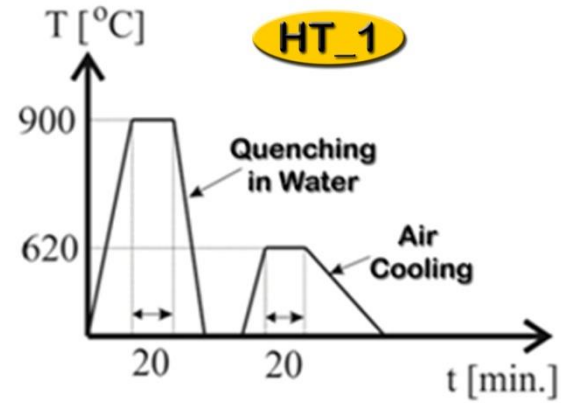
Not affected tempered martensite

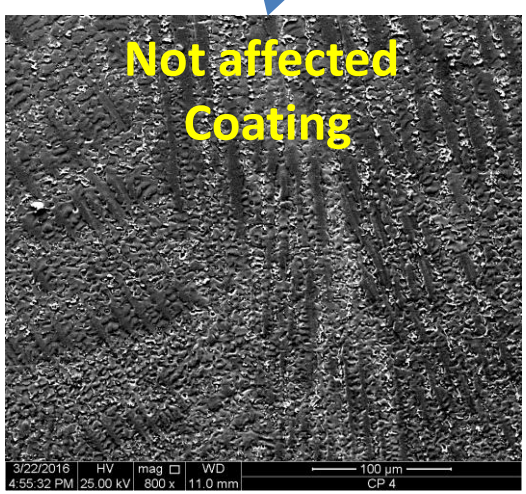
Results and Discussion

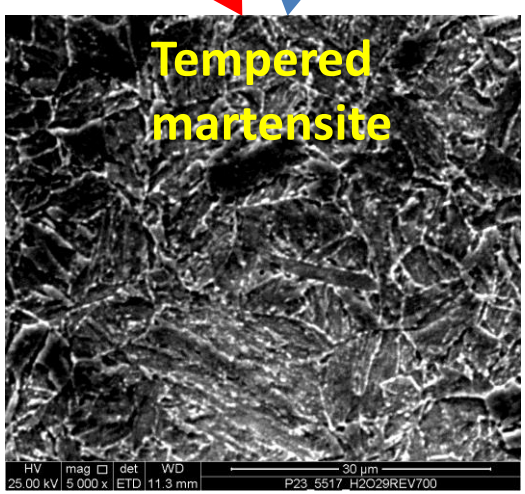
Heat Treatment after Coating Deposition

Hardness profile: condition HT 1









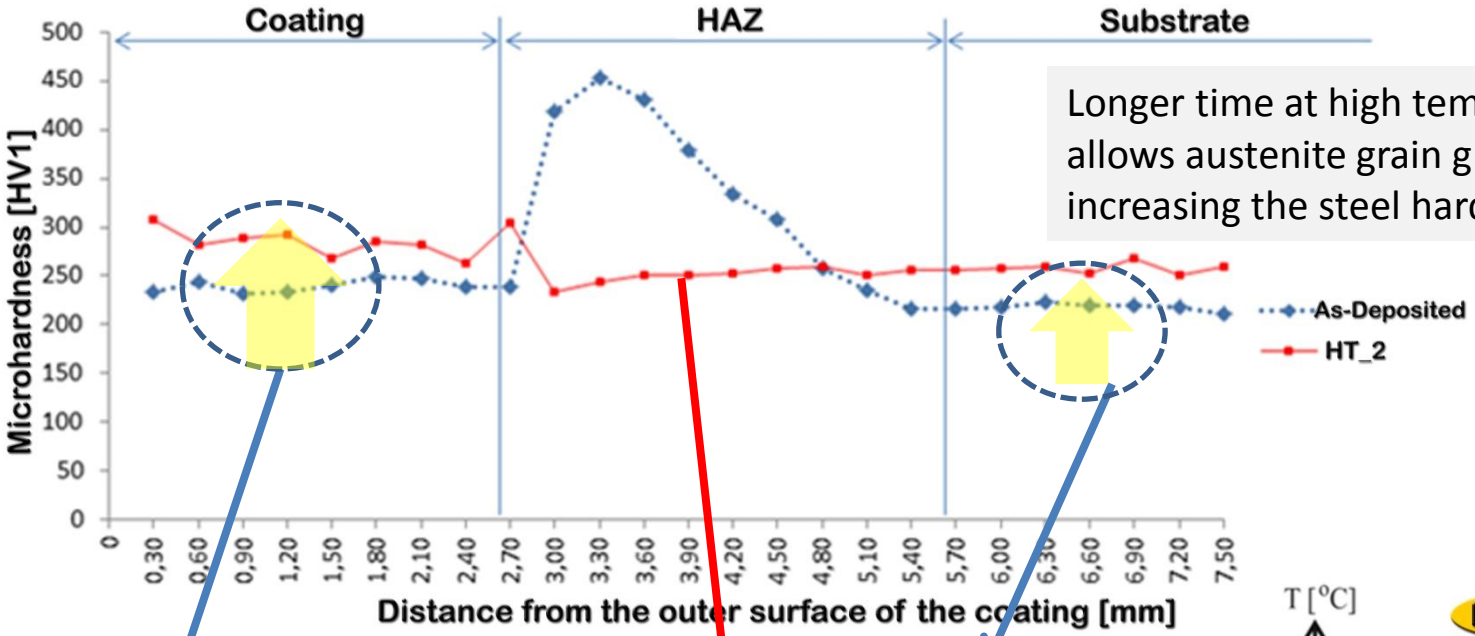
After the first heat treatment, there was no change in the hardness of the coating and the hardness of the steel.

However, the hardness of the HAZ decreases strongly due to austenitization and Q&T transforming the previous bainite into tempered martensite.

Results and Discussion

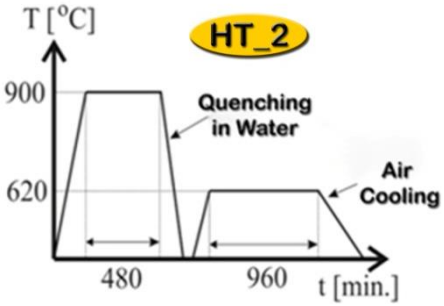
Heat Treatment after Coating Deposition

Hardness profile: condition HT 2



Longer time at high tempeature, allows austenite grain growth, increasing the steel hardenability!

Tempered martensite



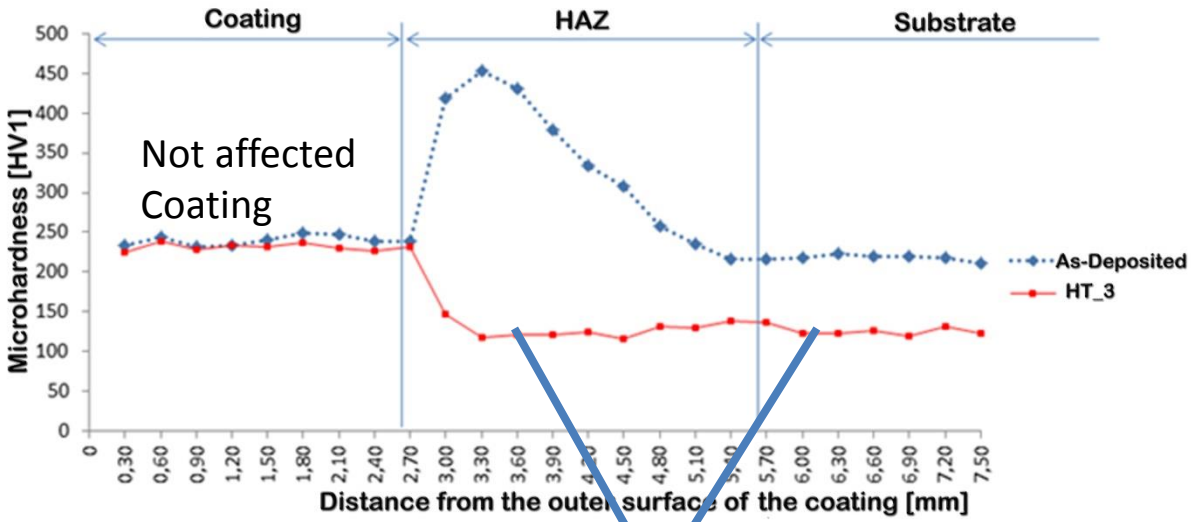
Due to longer time at high T, there is formation of δ (Ni_3Nb) phase, which increases the hardness of the Inconel 625.

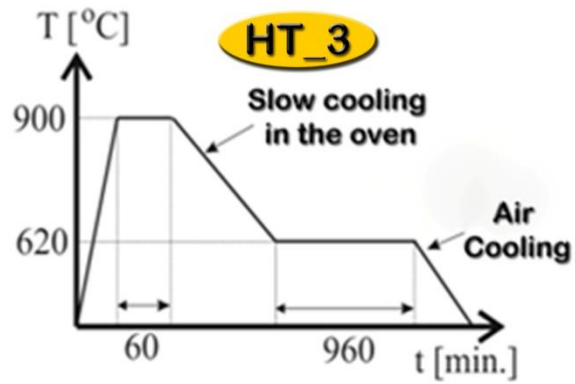
The hardness of the HAZ decreaces strongly due to austenitization and Q&T transforming the previous Bainite into tempered martensite.

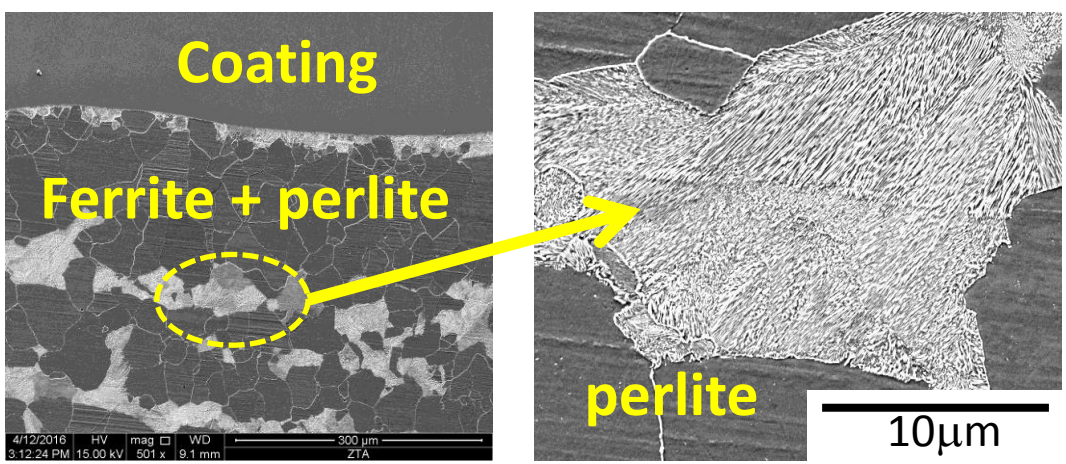
Results and Discussion

Heat Treatment after Coating Deposition

Hardness profile: condition HT 3







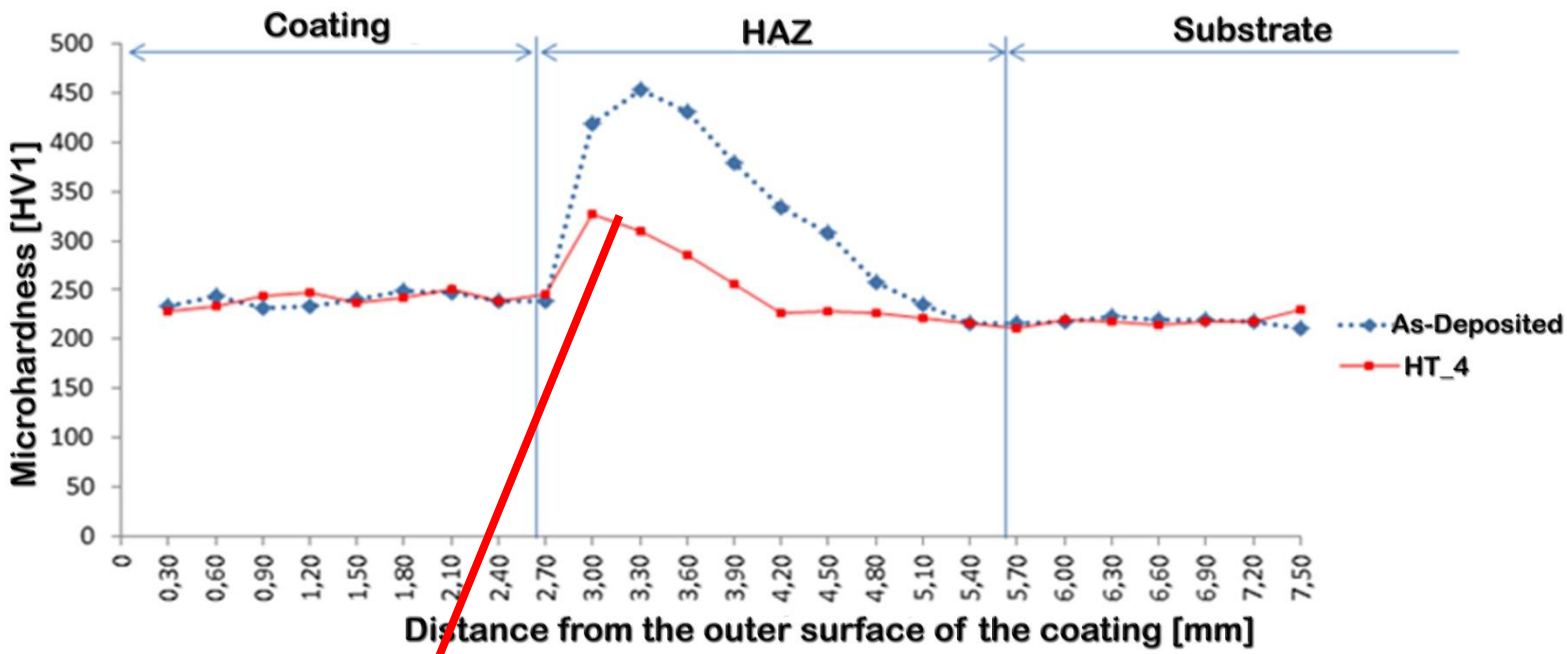
After the third heat treatment, there was no change in the hardness of the coating due to short soaking time.

On the other hand, the hardness of the HAZ and the substrate decrease strongly due to austenitization and the slow cooling forming ferrite + perlite microstructure.

Results and Discussion

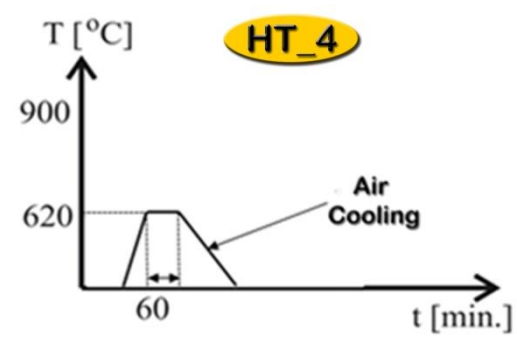
Heat Treatment after Coating Deposition

Hardness profile: condition HT 4



After this tempering, there was
no change in the hardness of the coating and the
steel due to lower temperature.

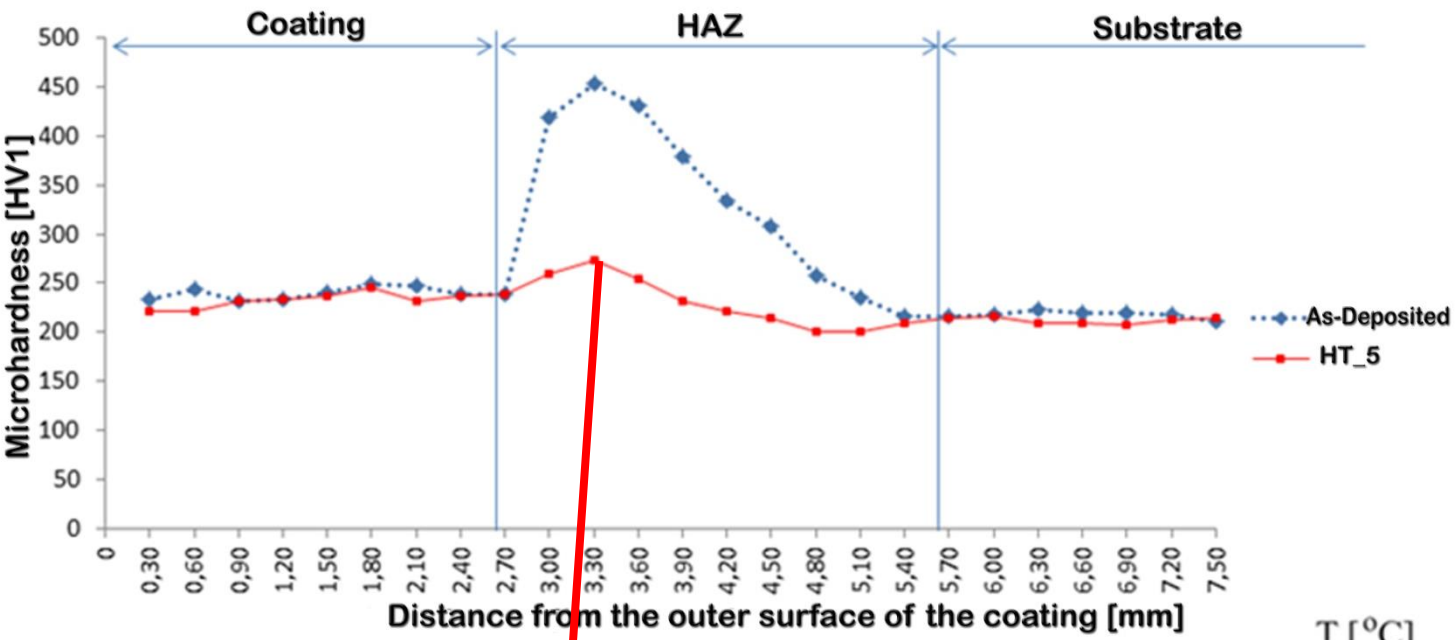
However, the hardness of the HAZ decreases
considerably due to coarsening of the carbide (cementite).



Results and Discussion

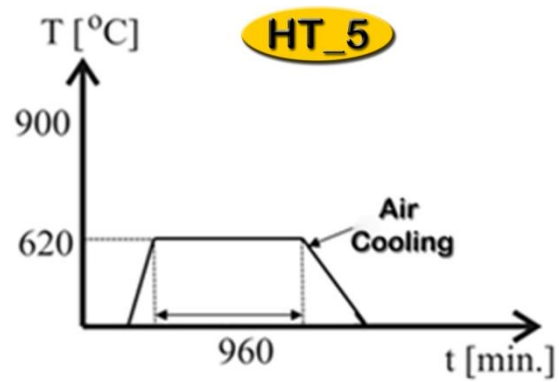
Heat Treatment after Coating Deposition

Hardness profile: condition HT 5



Even after this longer tempering, there was no change in the hardness of the coating and the steel due to lower temperature.

However, the hardness of the HAZ decreases strongly due to coarsening of the carbide, which increases with soaking time.



Conclusions

- ✓ The steel used presents an excellent hardenability, mainly due to the presence of Ti and B in the chemical composition. Jominy results confirm this important characteristics.
- ✓ After Inconel 625 Coating on the C-Mn steel it was observed a region with high hardness. This regions is called Heat Affected Zone (HAZ), which is formed due to the thermal gradient leading to bainite/martensite formation.
- ✓ The microstructure of the coating in the condition of as-deposited presents forms of columnar dendrites in the direction of heat extraction. Massive Mo and Nb carbides were observed within dendrites arms and fine Ti carbides in the matrix.
- ✓ Different heat treatments performed show the relationship between microstructure and the microhardness behavior of both materials: Coating and the steel.
- ✓ From these work is possible to choose the suitable heat treatment for such a hybrid system in such a way its fit to the production route and has good compromise between material performance and cost.

Thank you very much for your Attention.

Alan Maxuel

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