



5th International Symposium on Master Engineering *Booklets*



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Title: Design and Implementation of a Heat Treatment for the Recovery of Mechanical Properties of Stainless Steel Rollers in Hardening Furnaces

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Holdings

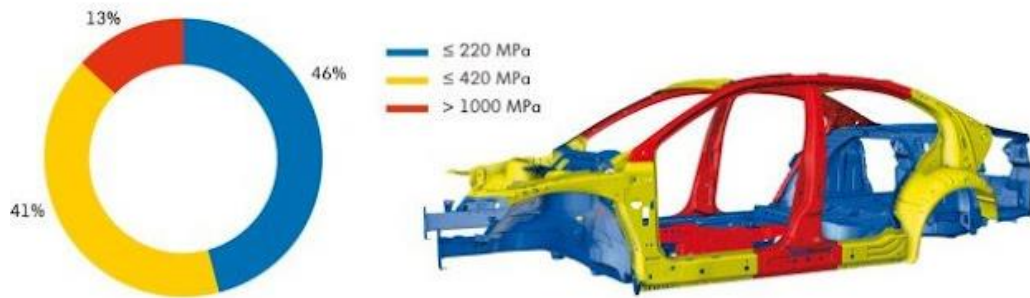
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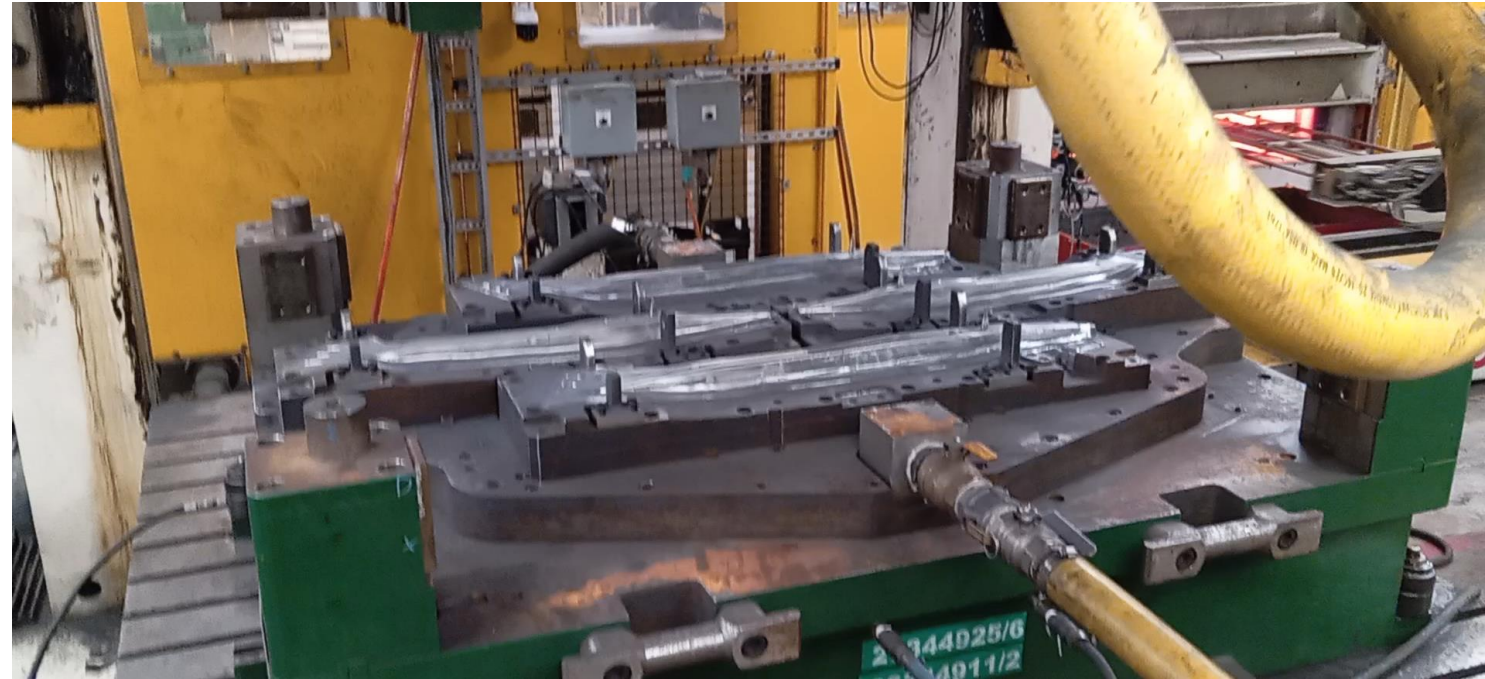
1.- Introducción



1.- Introducción

Hornos de sostenimiento

Proceso de Hot Stamping Press



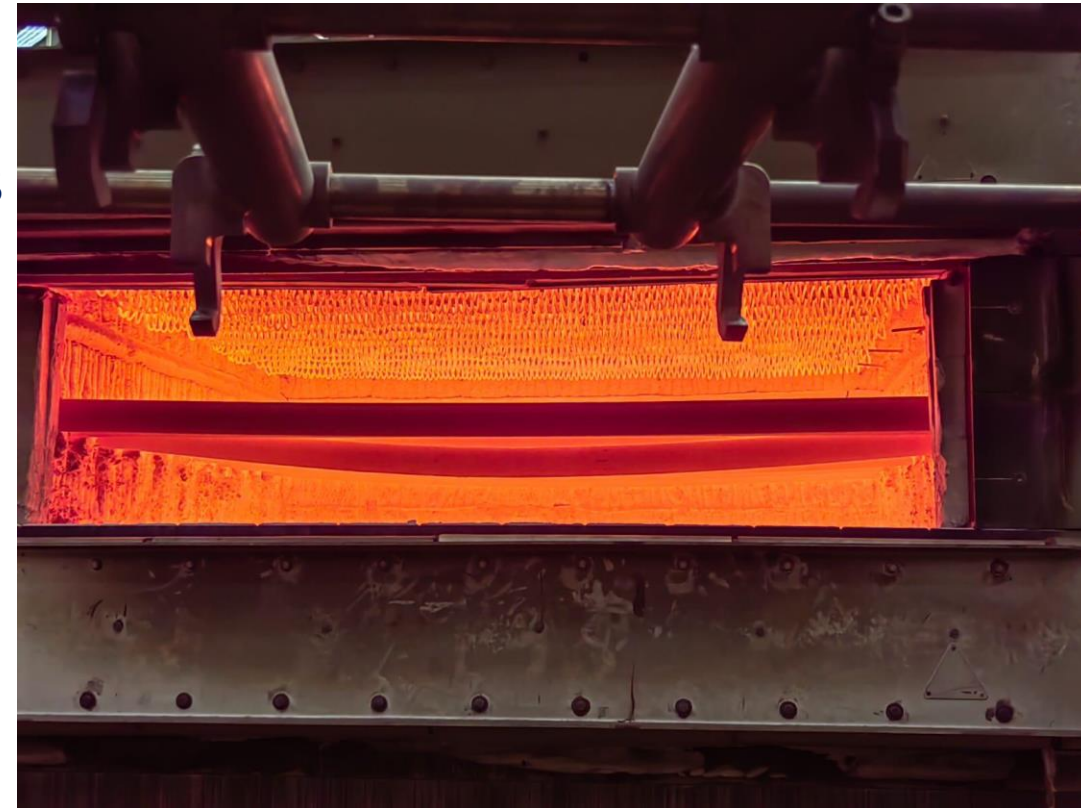
2 hornos por prensa

2.- Planteamiento del problema

ROLLERS



CERAMIC BRICKS



4 cavidades de operación de las cuales 2 son de rodillos

Temperatura de trabajo de 920°C a 970°C

2.- Planteamiento del problema



El desperdicio es de 264 rodillos por el cambio de 3 prensas, el costo total es de aproximadamente 528,000 USD Aprox.

Costo de cambio aproximado 2000 USD C/U



3.- Línea de tiempo





4.- Objetivo General

Desarrollar un tratamiento térmico que permita recuperar las propiedades mecánicas del acero inoxidable degradados en hornos de templado.

Objetivos específicos

Objetivo específico 1

Caracterizar por medio de microscopia óptica y medición de dureza en escala Vickers, el estado actual de los rodillos de acero inoxidable, identificando las fases presentes y su condición.

Objetivo específico 2

Diseñar un tratamiento térmico basado en la caracterización previa de los rodillos desgastados para el mejoramiento de la dureza y las fases detectadas.

Objetivo específico 3

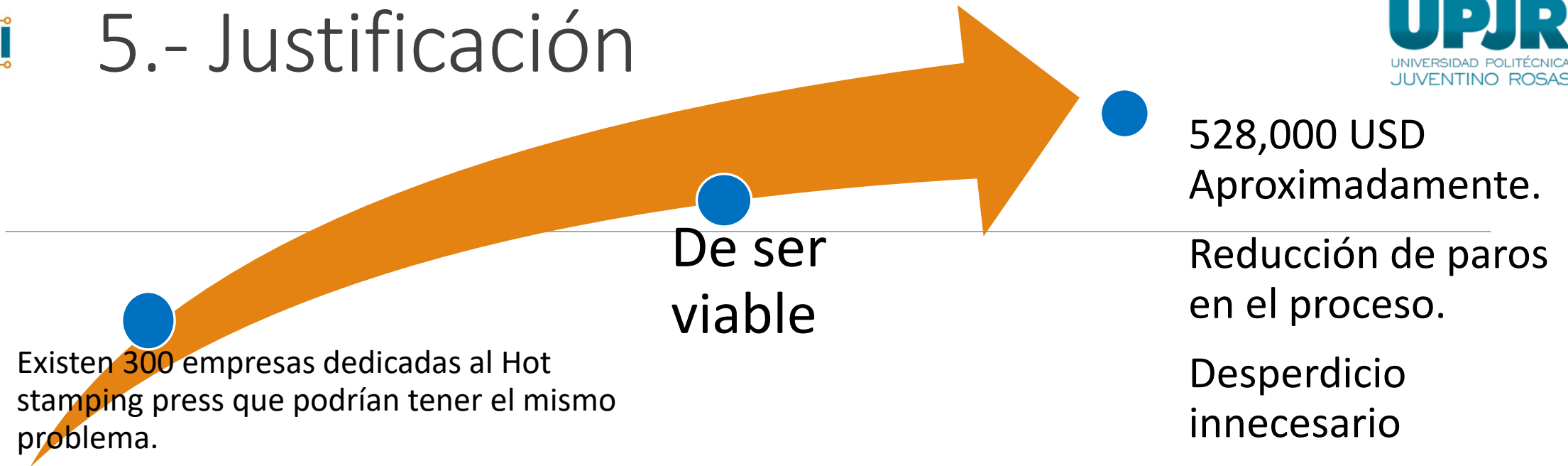
Realizar el tratamiento térmico a tiempos y temperaturas diseñados.

Objetivo específico 4

Emitir opinión técnica de los resultados obtenidos para su consideración en la industria.



5.- Justificación



6.- Limitaciones

Variaciones en el lote de producción, o condiciones las cuales no puedan ser controladas por el proveedor original

223.52 cm



Ausencia de datos originales precisos sobre la composición química del acero inoxidable utilizado

7.- Caracterización

7.1 Pruebas



T1	Material nuevo
T2	Pandeado con 2 rectificadas sin usar
T3	Primer rectificada sin usar
T4	Pandeado 3 usado



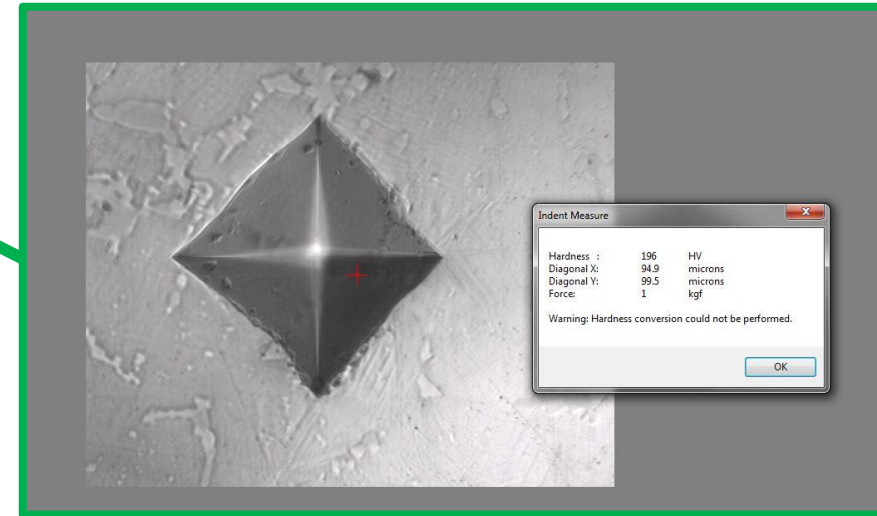
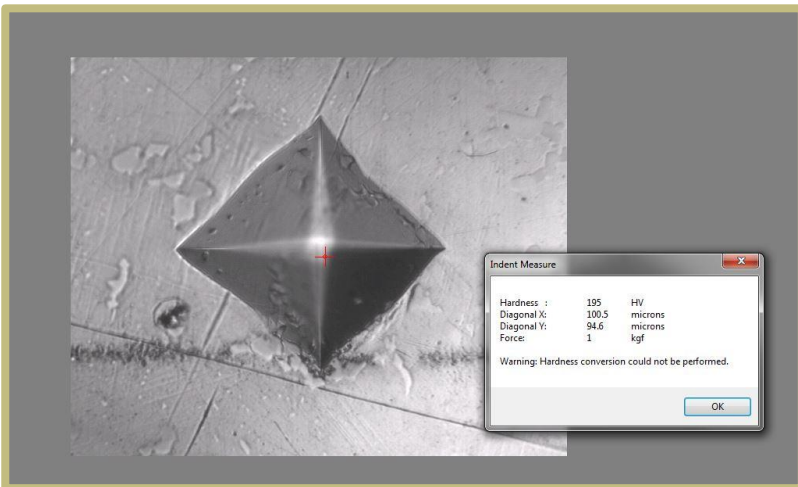
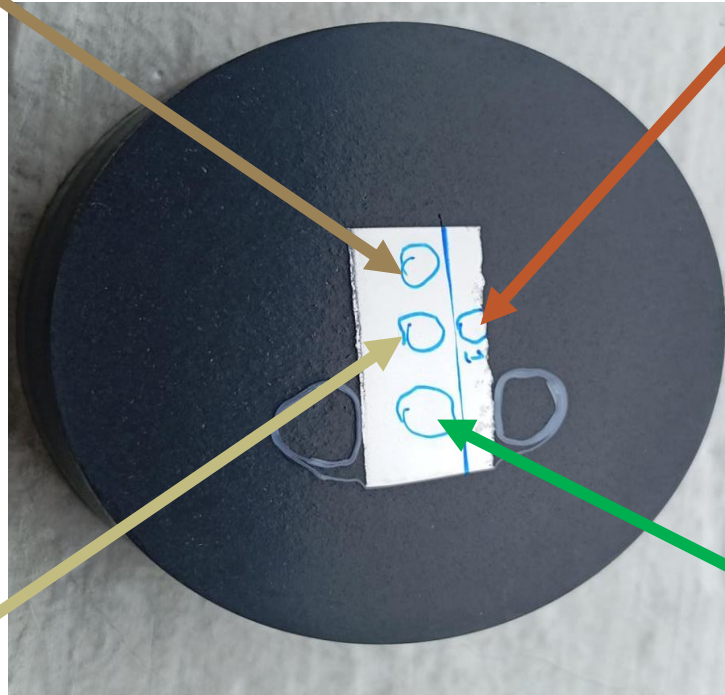
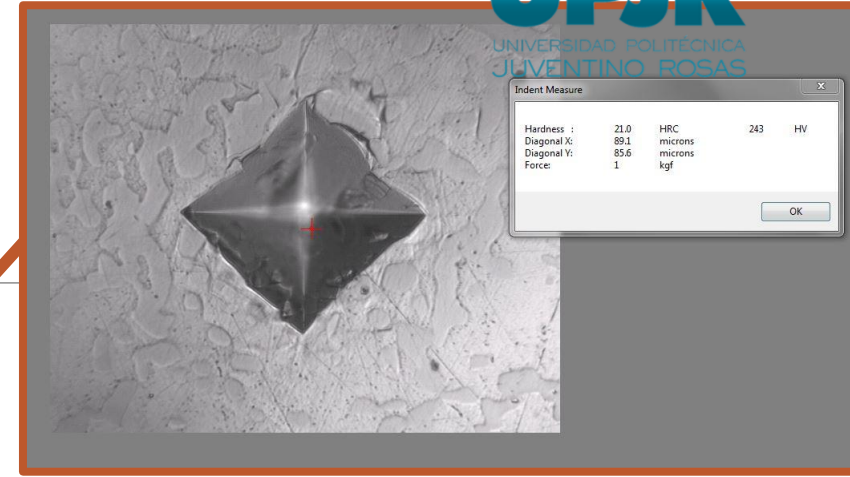
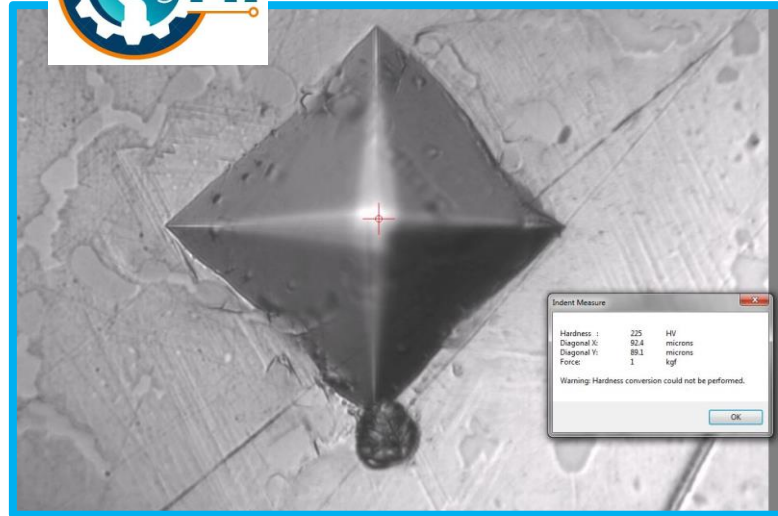
7.1.1 Microestructura T4

ZONA 3
205 HRV

ZONA 4
243 HRV

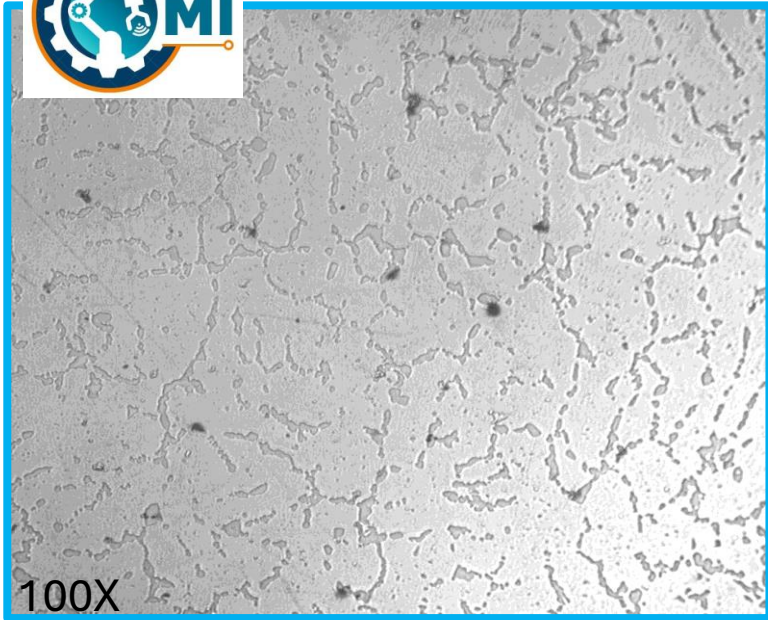
ZONA 2
195 HRV

ZONA 1
196 HRV

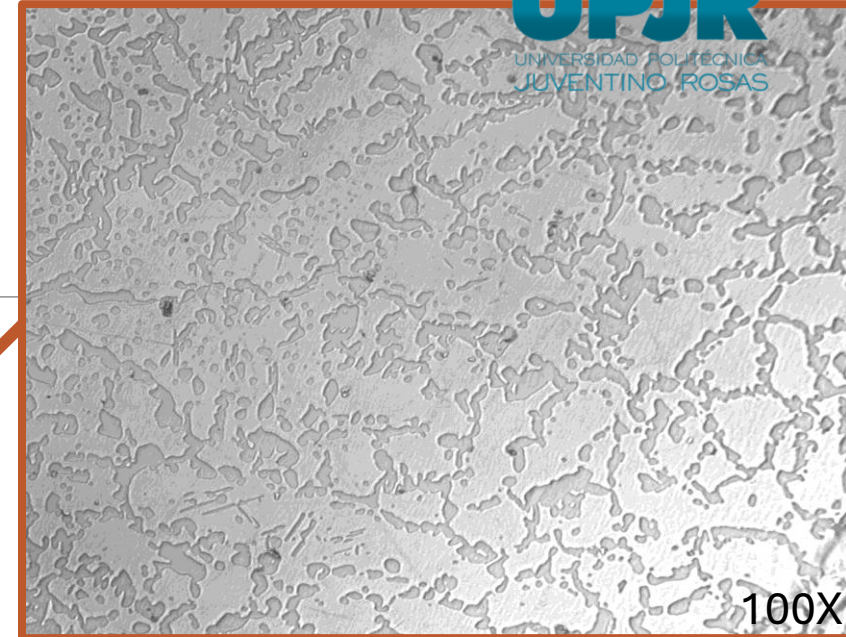




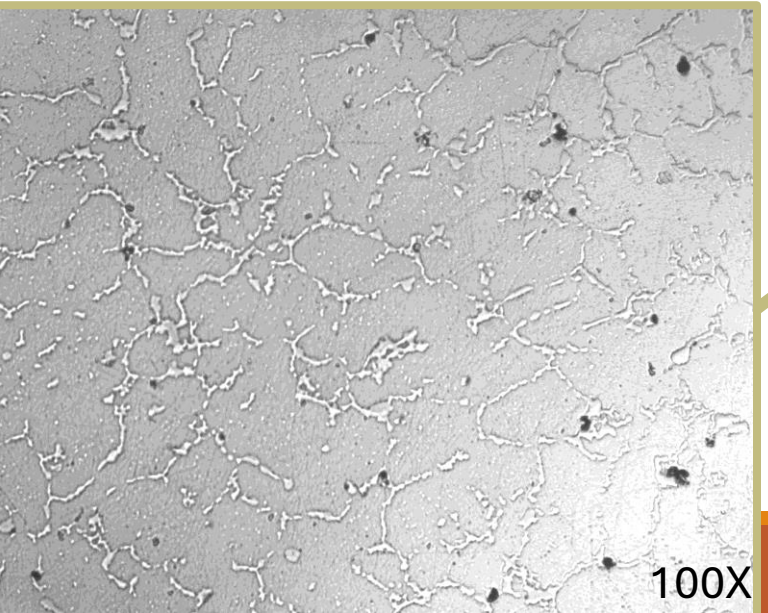
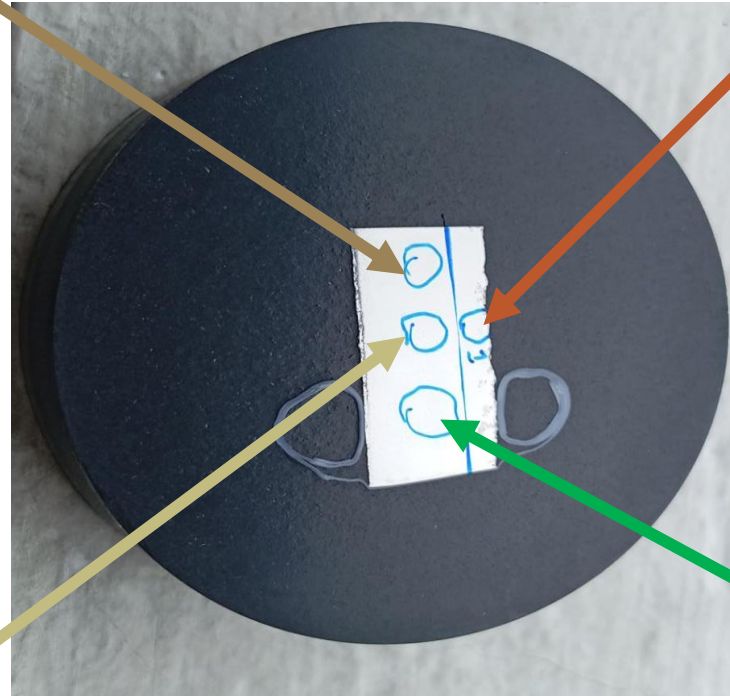
7.1.2 Microestructura T4



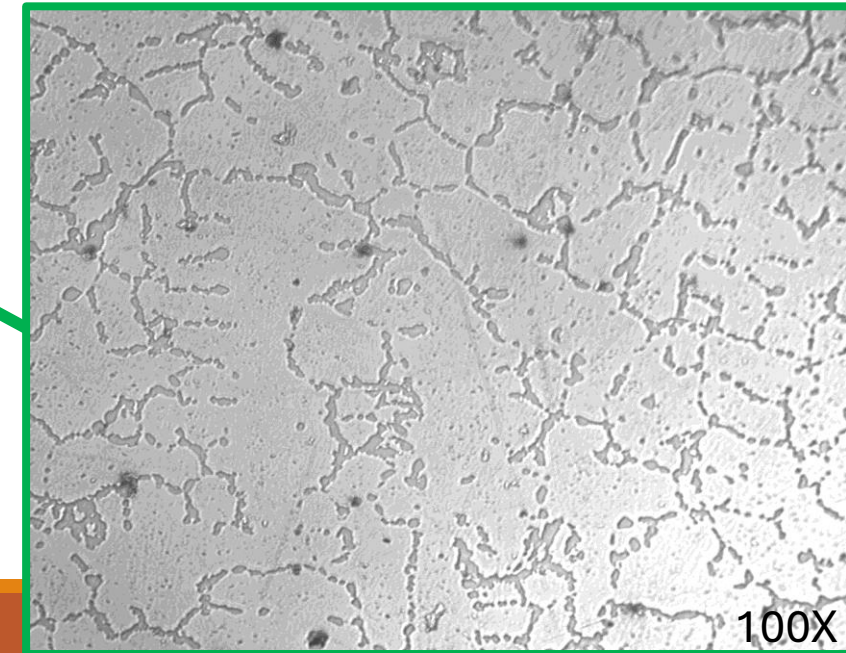
ZONA
3



ZONA 4

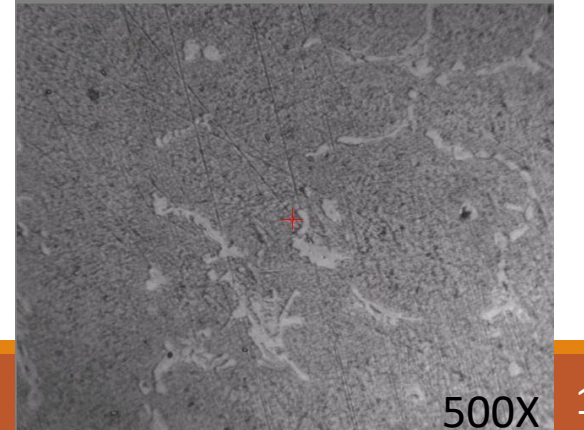
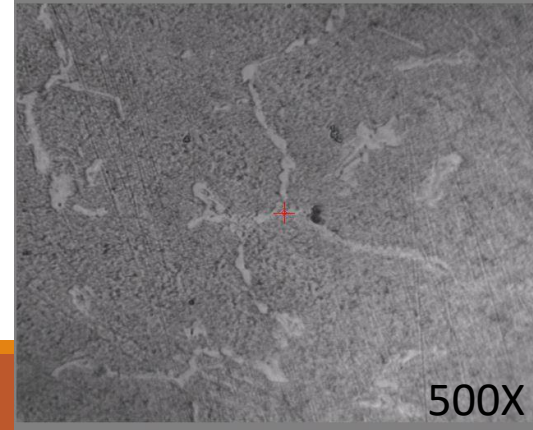
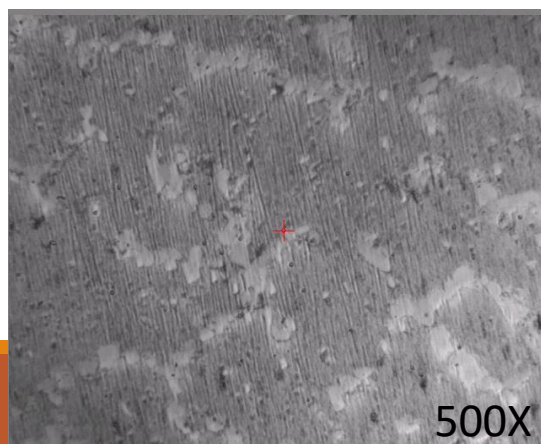
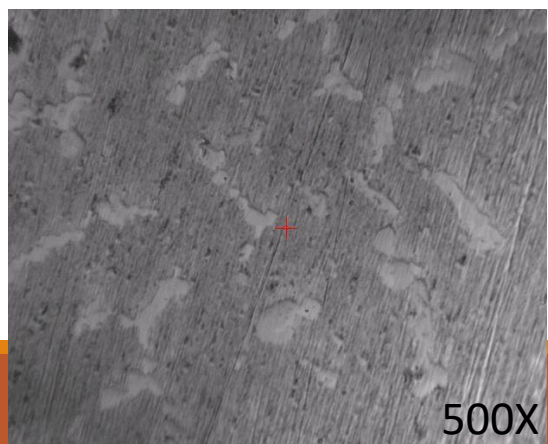
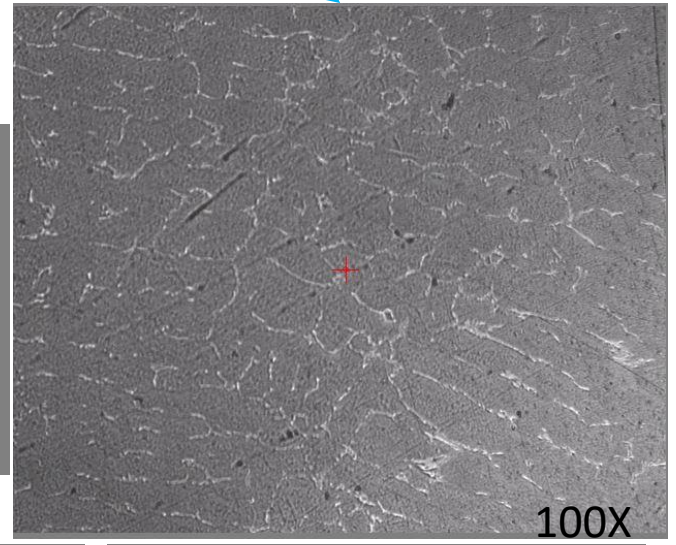
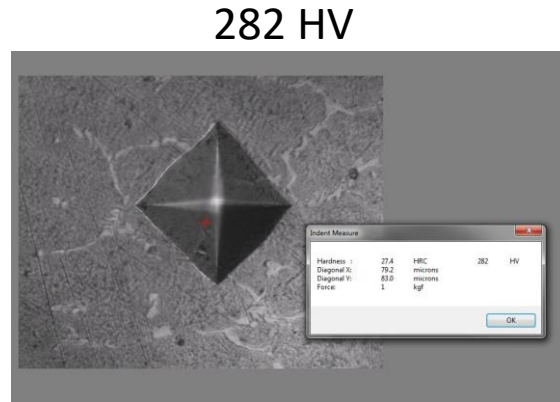
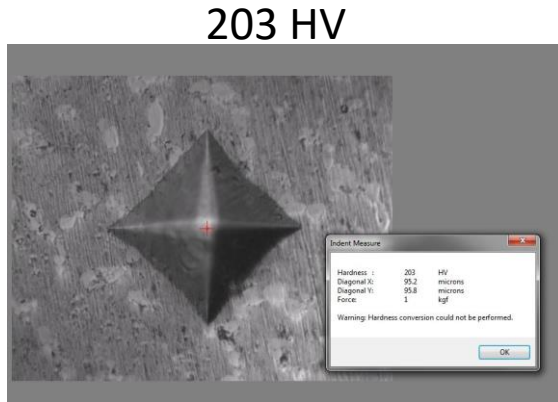
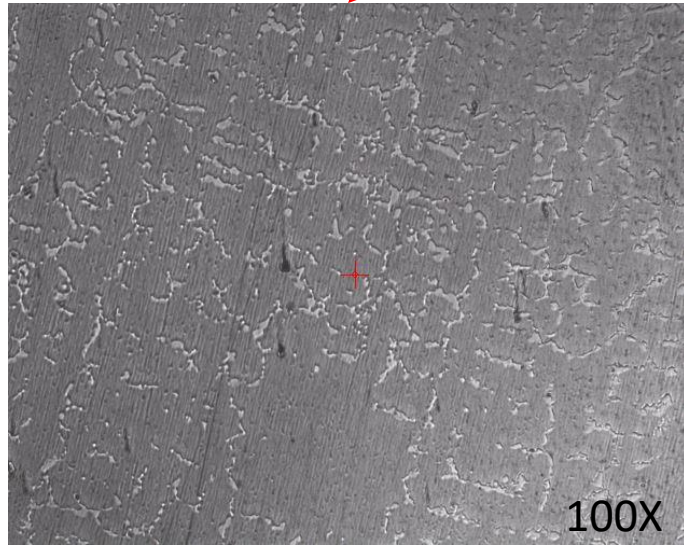


ZONA
2

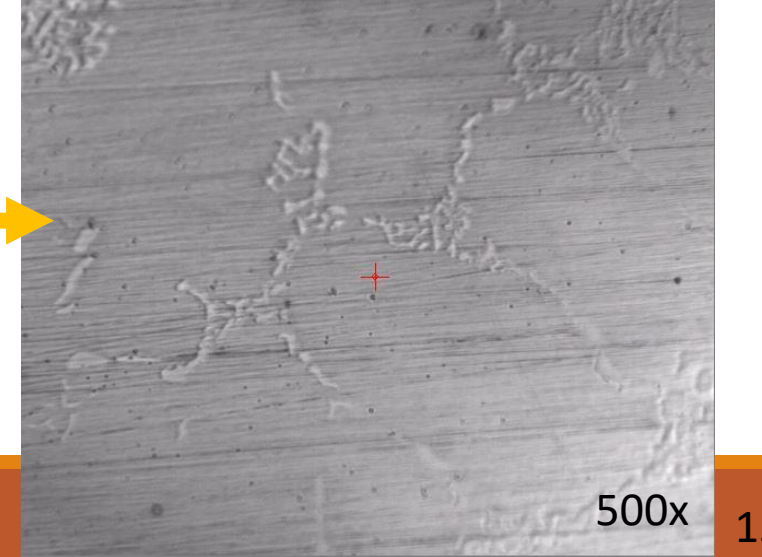
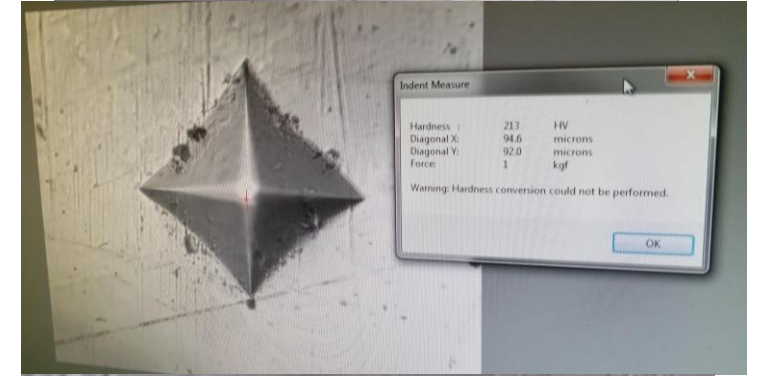
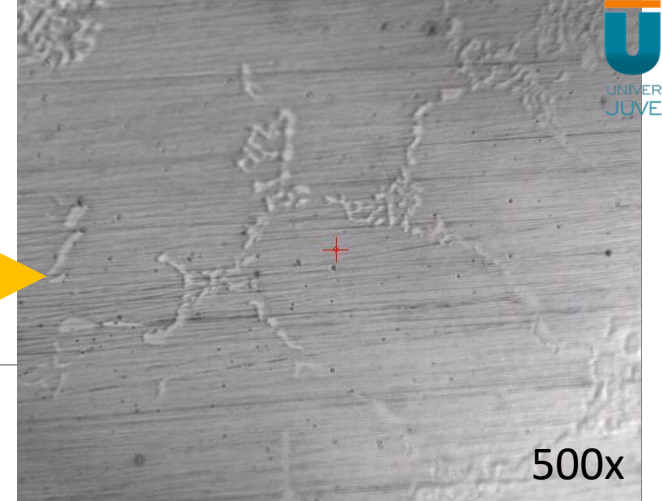
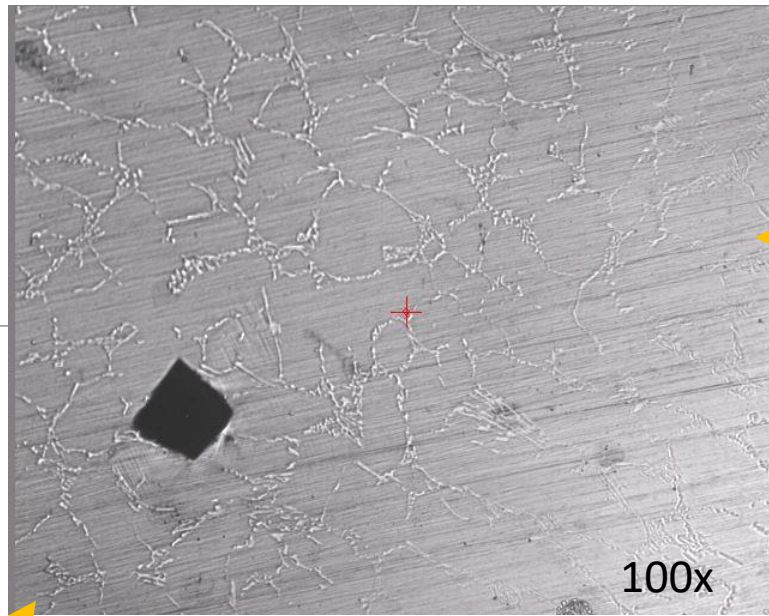


ZONA 1

7.1.3 Micrografías T3



7.1.4 Nuevo Rodillo



7.2 Equipo de Caracterización



Difractómetro Inel, modelo EQUINOX 2000
Radiación con una lámpara de
cobalto (CoK_α) con una longitud de
onda 1.78 \AA .

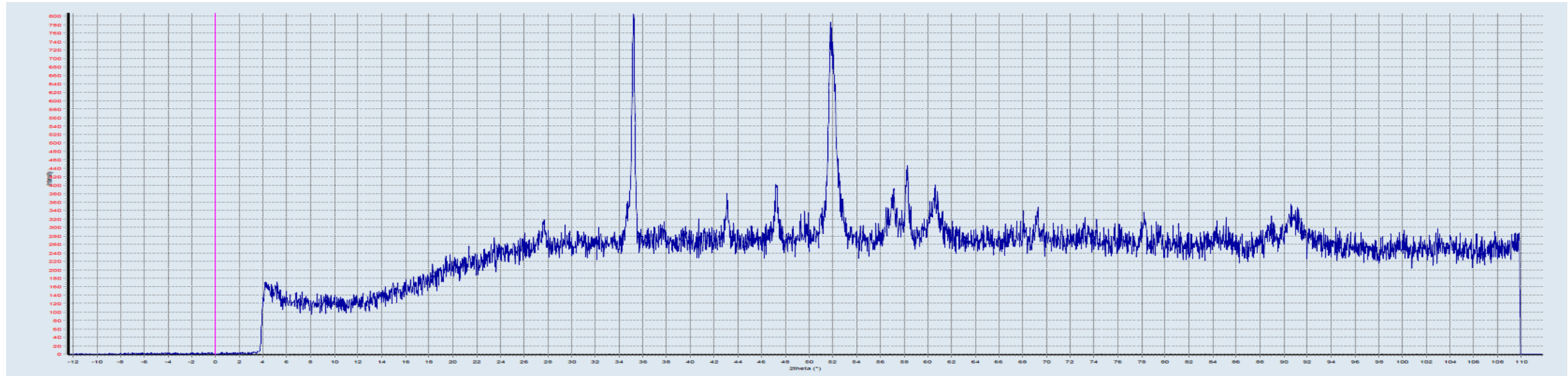


JSM-IT300 InTouchScope™ Scanning Electron Microscope

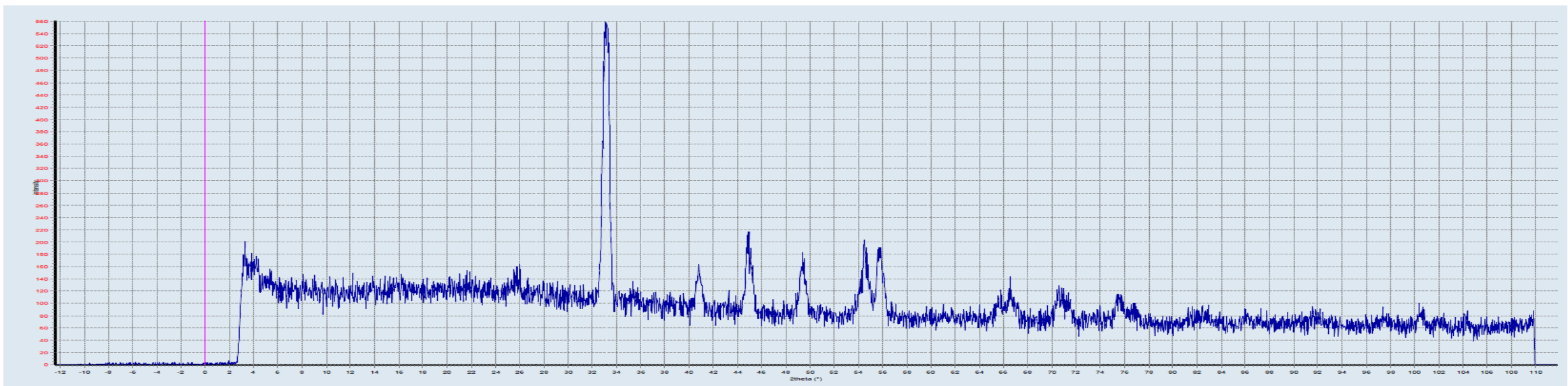


T3

7.3 Caracterización

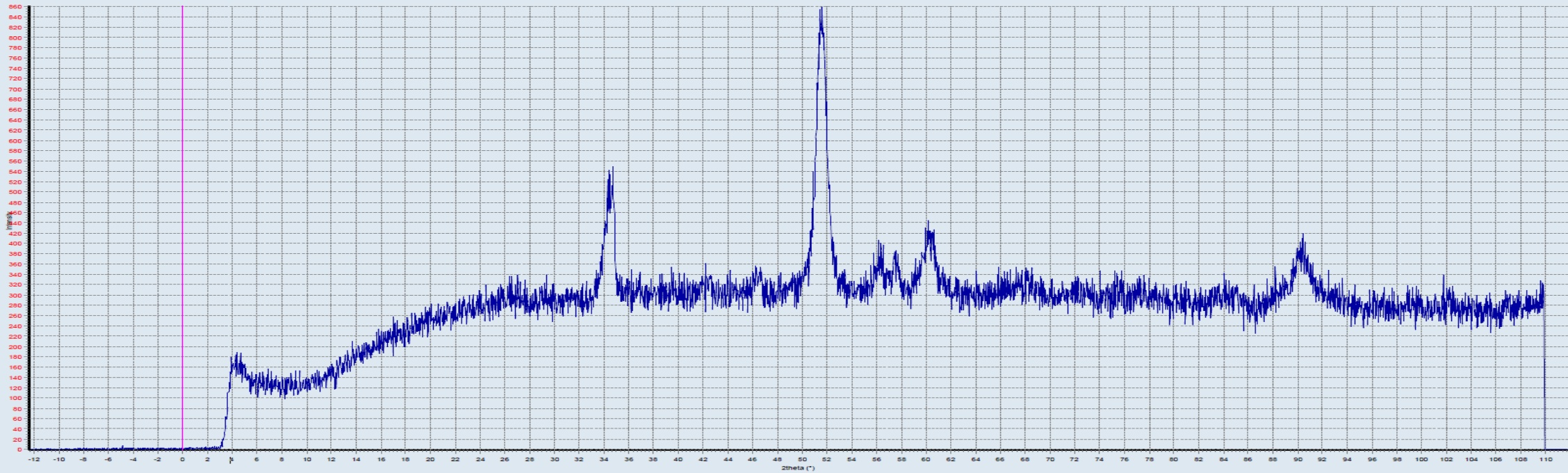


T1

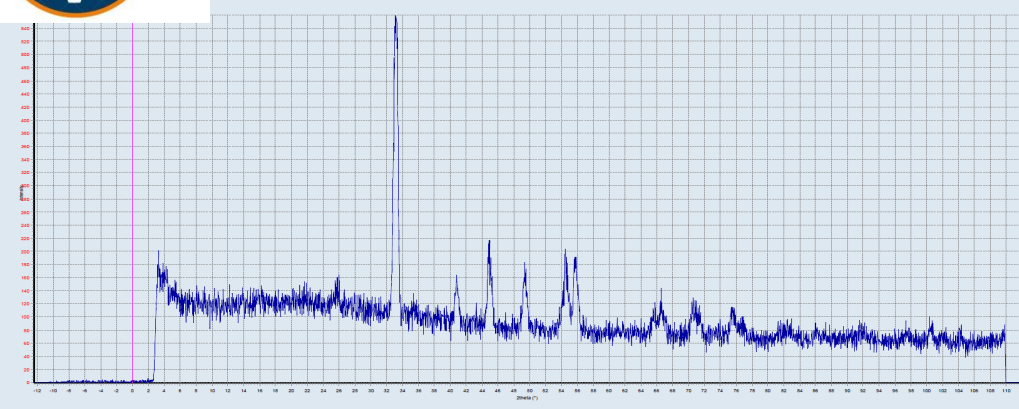


Difractograma de muestra

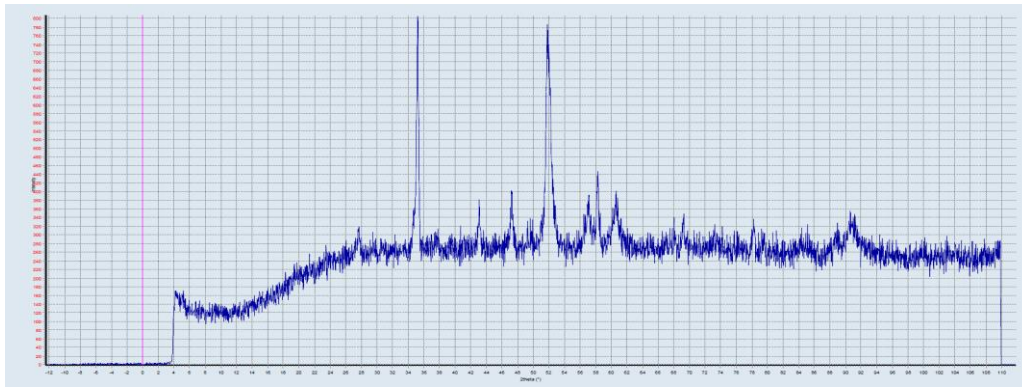
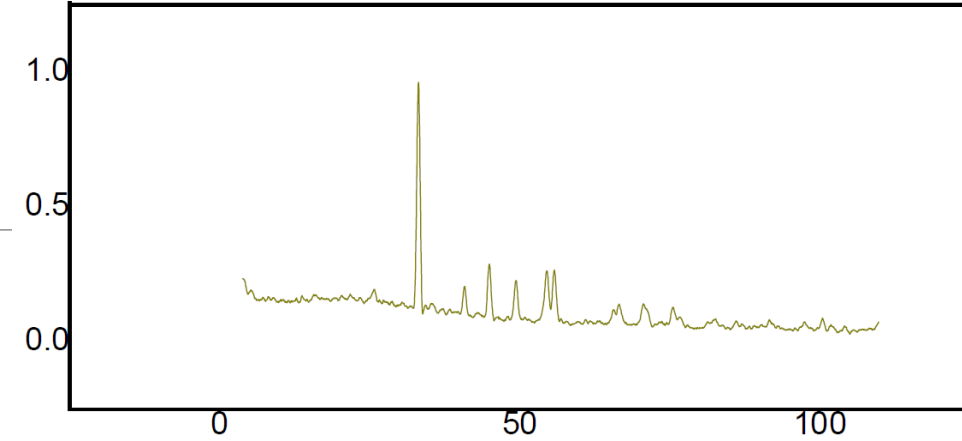
7.3 Caracterización T4



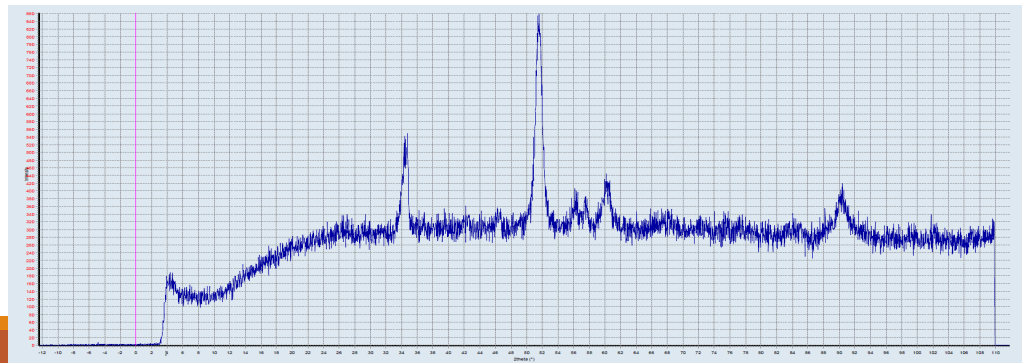
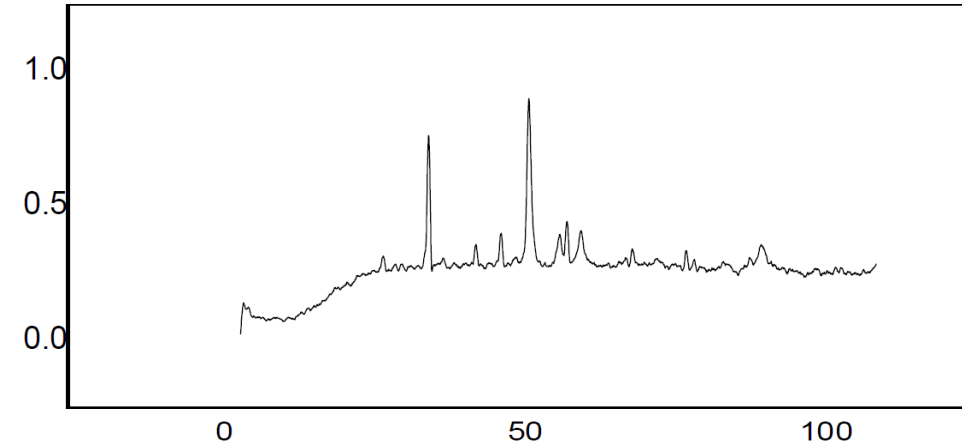
7.3.1 Caracterización Origin Pro 8



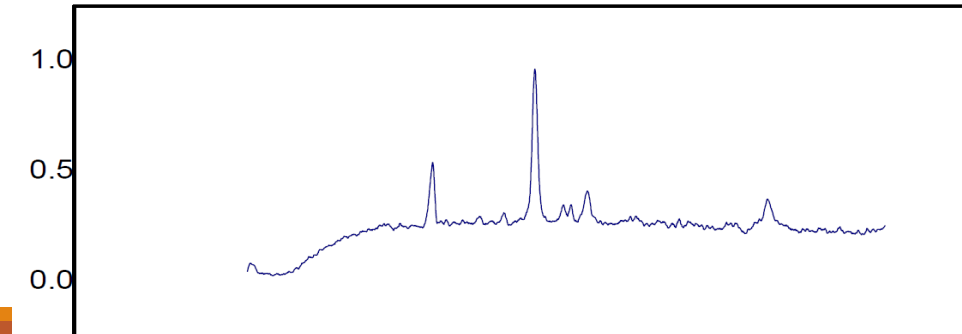
T1



T3

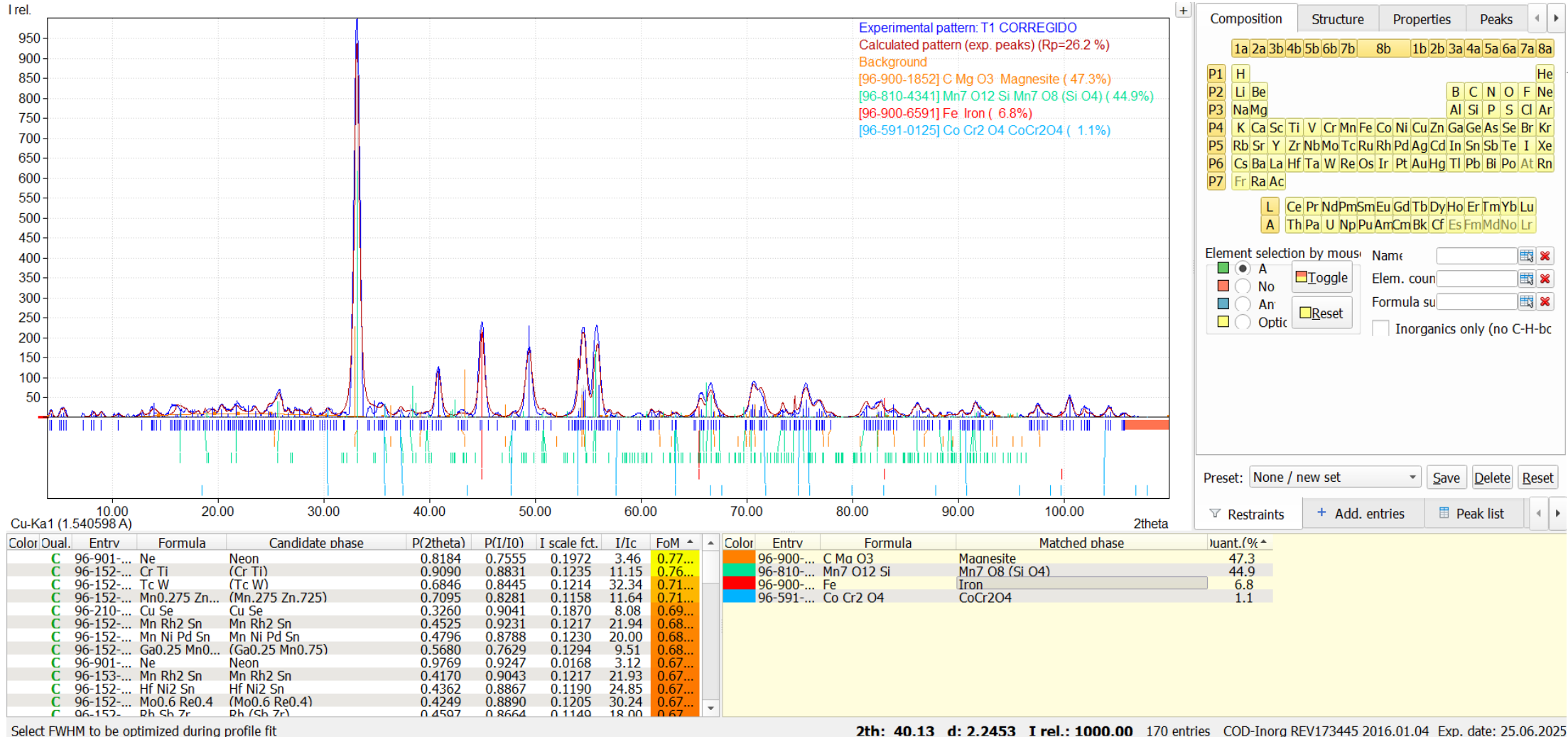


T4



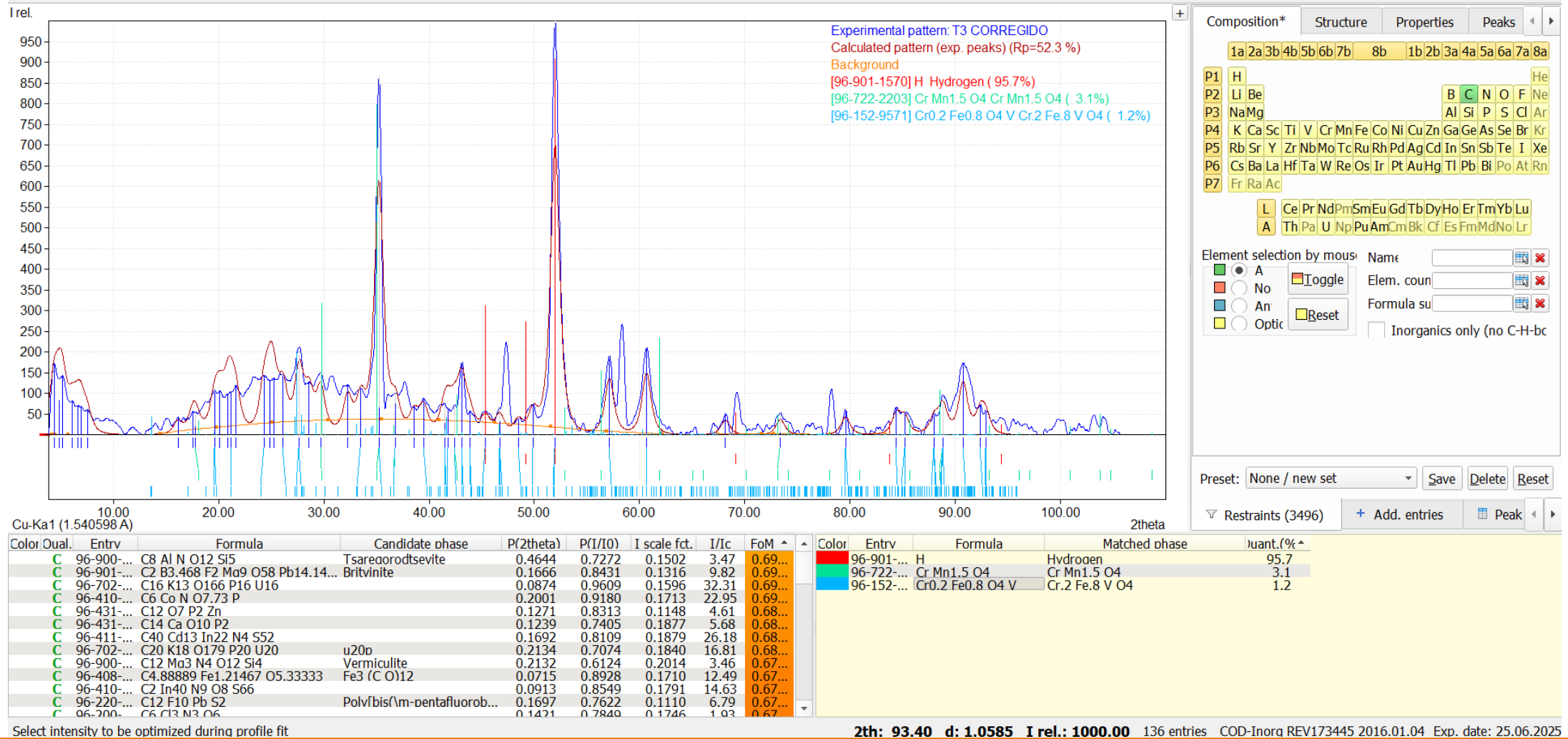


7.3.2 Caracterización DRX (MATCH) T1





7.3.3 Caracterización DRX (MATCH) T3



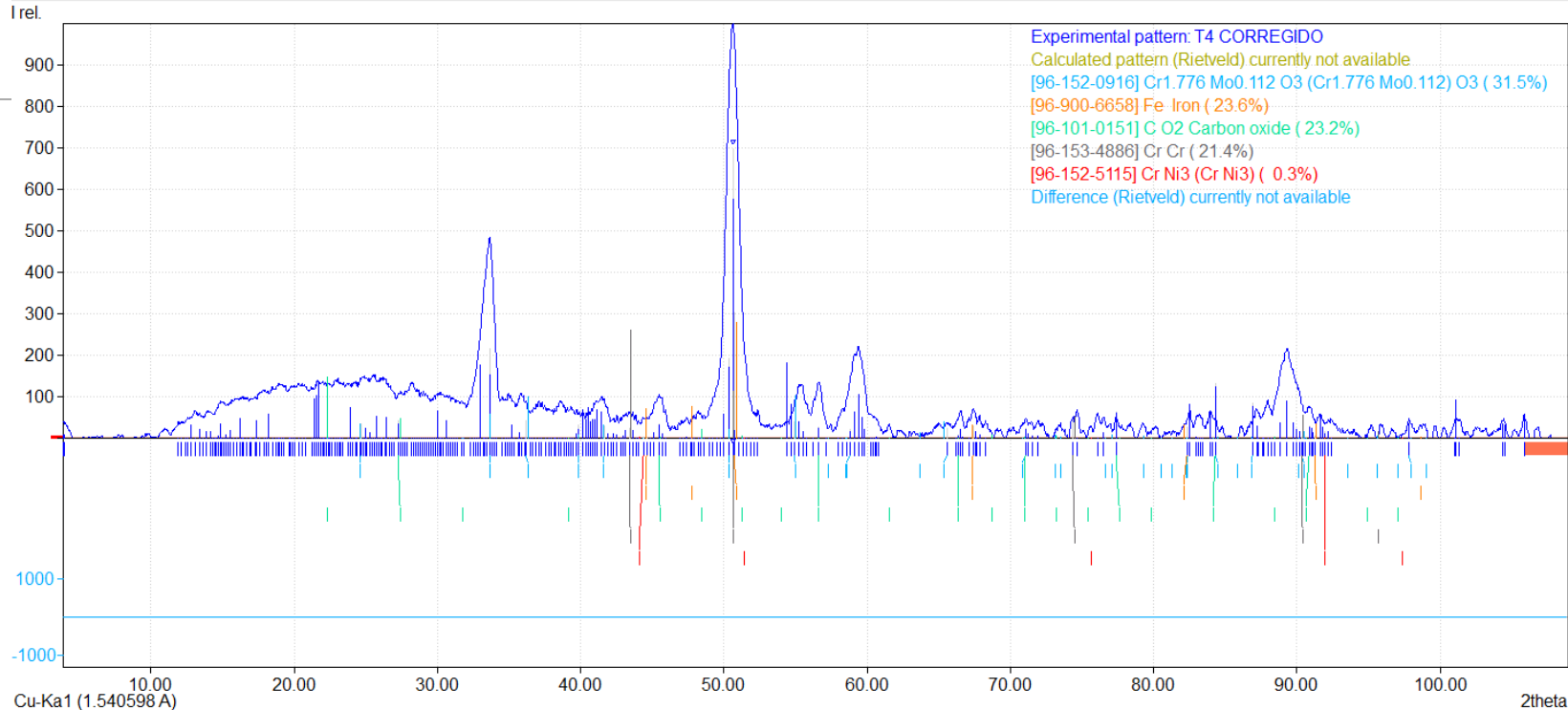
2th: 93.40 d: 1.0585 I rel.: 1000.00 136 entries COD-Inora REV173445 2016.01.04 Exp. date: 25.06.2025



7.3.4 Caracterización DRX (MATCH) T4

Espectrometría

Muestra	Material doblado	Rodillo 1
Elemento	% promedio	
C	1.4	0.938
Mn	1.99	1.41
Si	>5	2.88
P	0.102	0.0781
Si	0.0271	0.0092
Cr	>5	>5
Mo	0.634	0.911
Ni	>4.5	>4.5
Al	0.0183	0.0182
Co	0.212	0.166
Cu	0.16	0.103
Nb	0.087	0.0496
Ti	0.0083	0.0287
V	0.0972	0.0807
W	0.0908	0.0458
Pb	0.0332	0.0088
Sn	0.0127	0.0108
As	0.0358	0.0629
Zr	0.0121	<0.004
Ca	>0.005	>0.005
B	0.0094	0.0012
Zn	>0.03	>0.03
Fe	56.2	60.1



Color	Dual	Entrv	Formula	Candidate phase	P(2theta)	P(I/I0)	I scale fct.	I/Ic	FoM	Color	Entrv	Formula	Matched phase	Quant.(%)
C		96-901-...	Ne	Neon	0.8806	0.7672	0.1570	3.40	0.76...		96-152-...	Cr1.776 Mo0.112 O3	(Cr1.776 Mo0.112) O3	31.5
C		96-152-...	Ga0.33 ...	Sr Mn0.67 Ga0.3...	0.8223	0.7194	0.1530	10.55	0.73...		96-900-...	Fe	Iron	23.6
C		96-110-...	Co La M...		0.8233	0.7208	0.1541	12.03	0.73...		96-101-...	C O2	Carbon oxide	23.2
C		96-900-...	Cd Pr		0.6149	0.9084	0.1768	28.94	0.73...		96-153-...	Cr	Cr	21.4
C		96-152-...	Tl Yb	Tl Yb	0.6369	0.8916	0.1751	42.18	0.73...		96-152-...	Cr Ni3	(Cr Ni3)	0.3
C		96-153-...	Te Th	Th Te	0.7845	0.7407	0.1606	36.72	0.73...					
C		96-721-...	O2.93 ...	Strontium Vanadi...	0.8039	0.7070	0.1510	9.06	0.72...					
C		96-153-...	Ha6.4 I...	Ha6.40 In1.60	0.6961	0.7232	0.1622	33.62	0.72...					
C		96-151-...	O3 Sr V	Strontium Vanadi...	0.7988	0.7028	0.1503	8.96	0.72...					
C		96-153-...	Tl Tm	Tl Tm	0.5920	0.8920	0.1751	41.94	0.72...					
C		96-400-...	La0.2 M...		0.8174	0.6786	0.1519	11.10	0.72...					
C		96-152-...	Ca0.2 F...	(Ca0.2 Sr0.8) (Fe...	0.7741	0.7062	0.1505	9.14	0.72...					
C		96-151-...	O3 Sr V	Strontium Vanadi...	0.8138	0.6646	0.1480	9.20	0.72...					

Composition Structure Properties Peaks

1a 2a 3b 4b 5b 6b 7b 8b 1b 2b 3a 4a 5a 6a 7a 8a

P1 H He
P2 Li Be B C N O F Ne
P3 Na Mg Al Si P S Cl Ar
P4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
P5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
P6 Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
P7 Fr Ra Ac

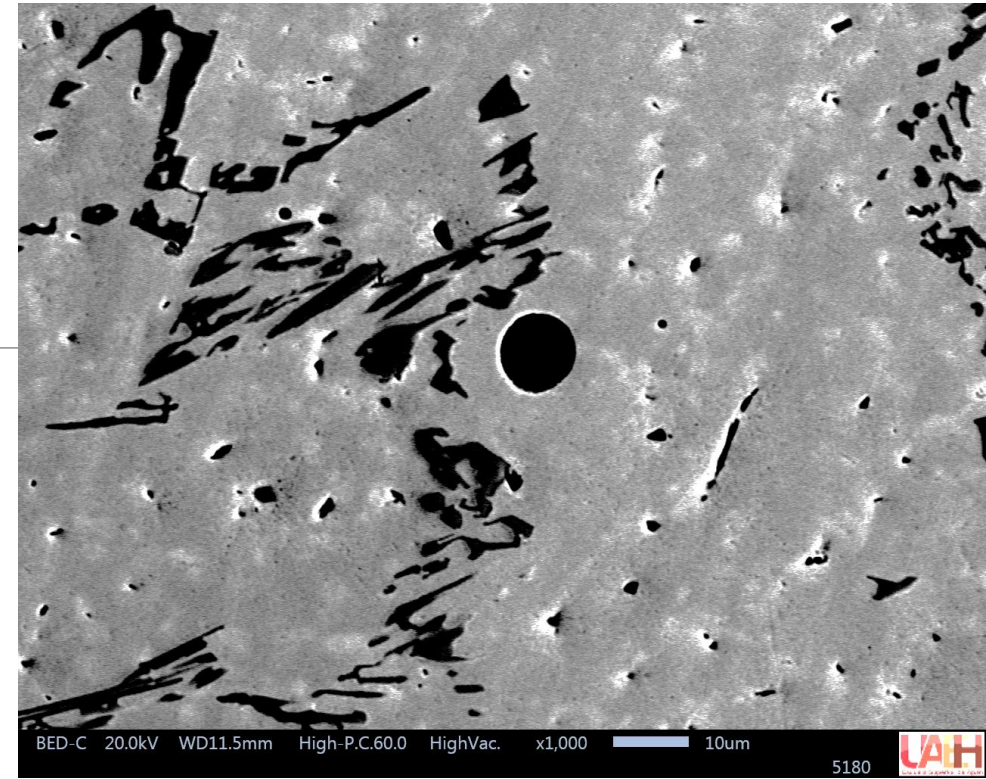
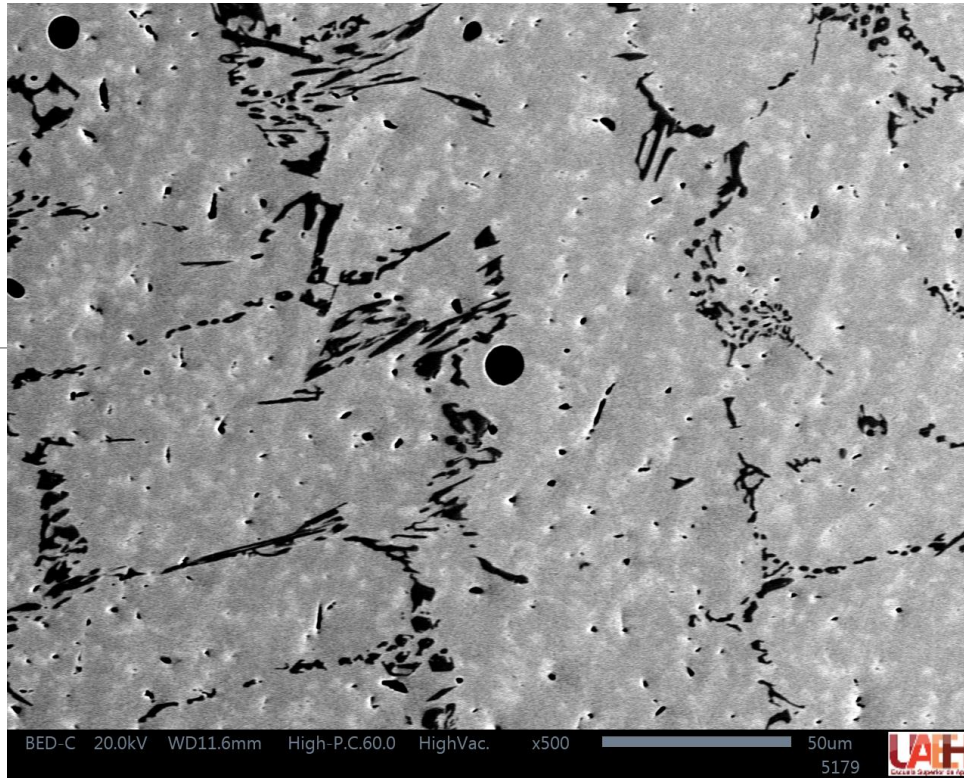
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A Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

Element selection by mouse: Name, Elem. coun, Formula su, Inorganics only (no C-H-bc)

Preset: None / new set Save Delete Reset

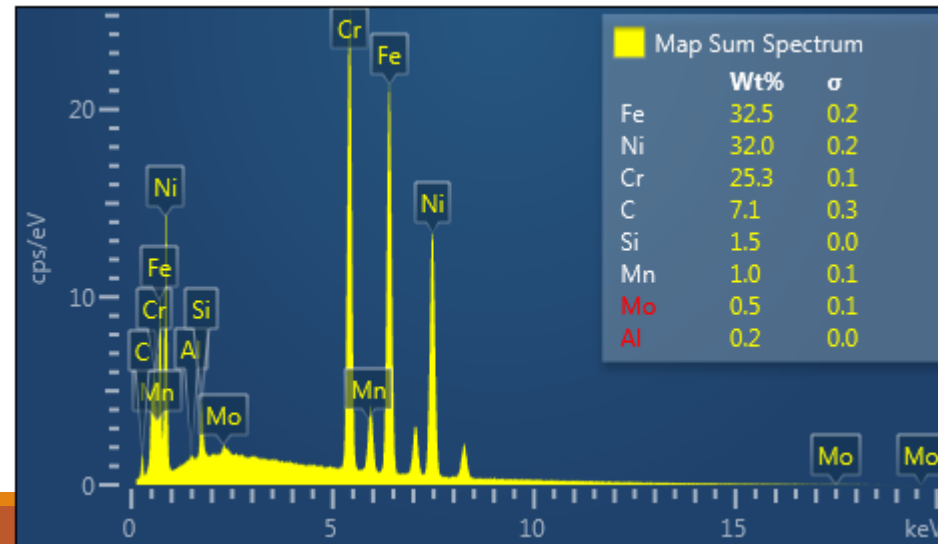
▽ Restraints + Add. entries Peak list

Select FWHM to be optimized during profile fit 2th: 102.89 d: 0.9850 I rel.: 1000.00 1350 entries COD-Inorg REV173445 2016.01.04 Exp. date: 25.06.2021



7.3.5

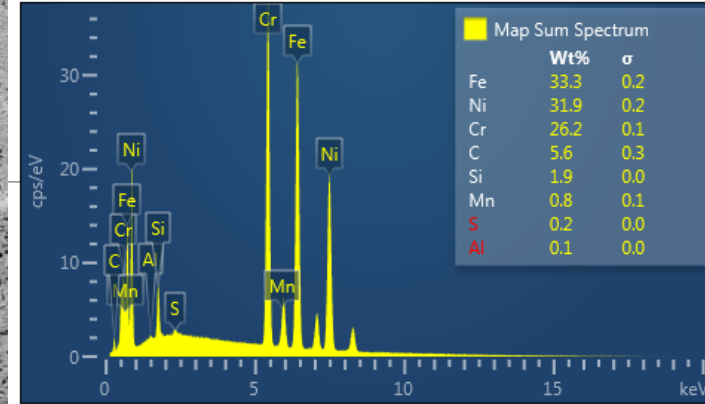
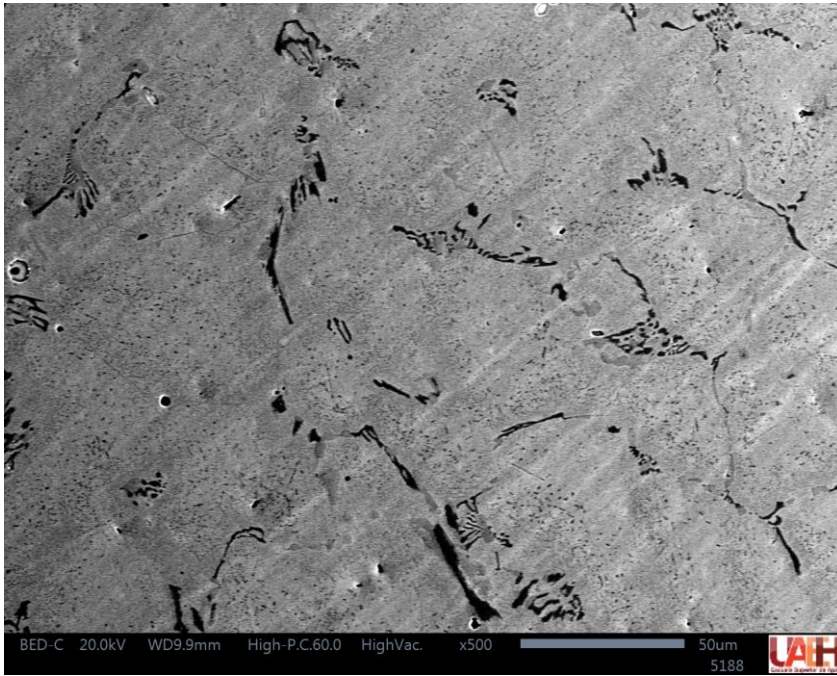
Caracterización MES Resultado T1



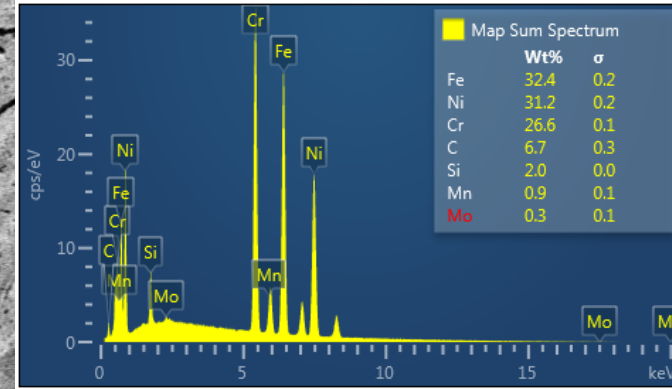
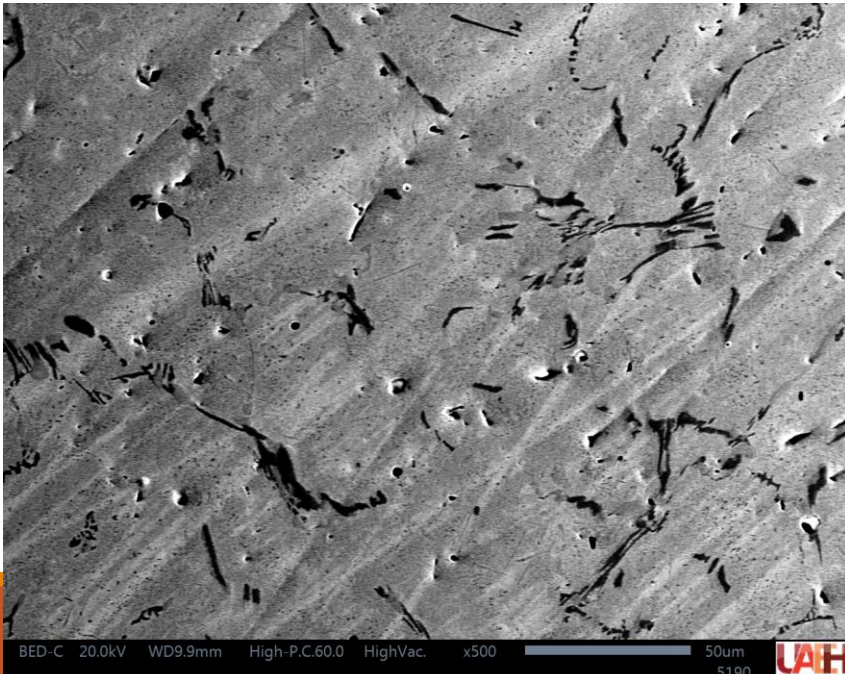


T3

Zona central

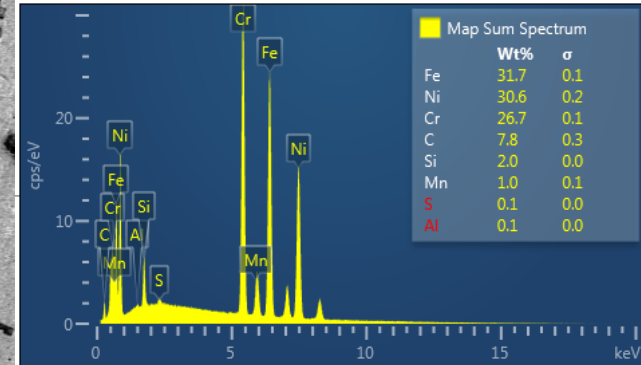
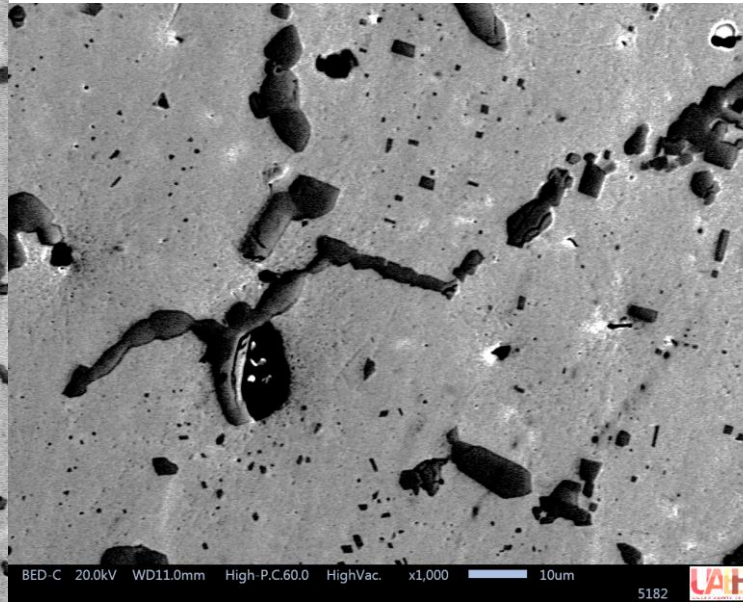
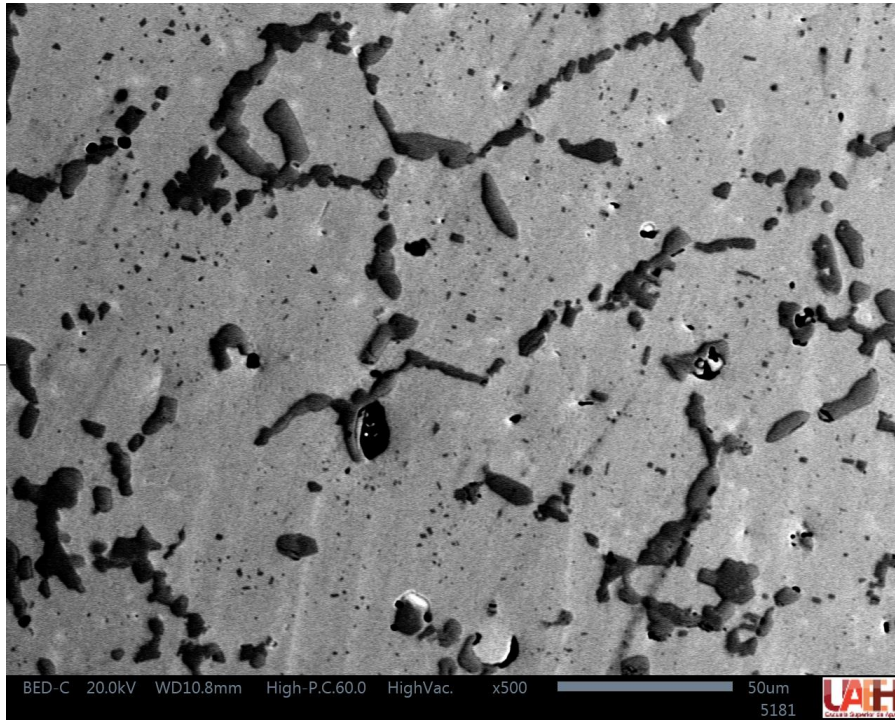


Zona superficial al 1 mm

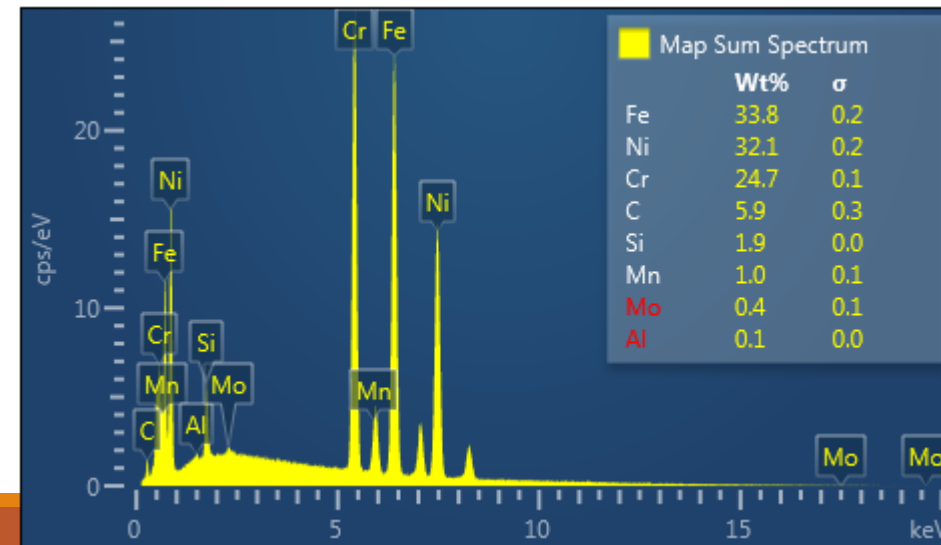
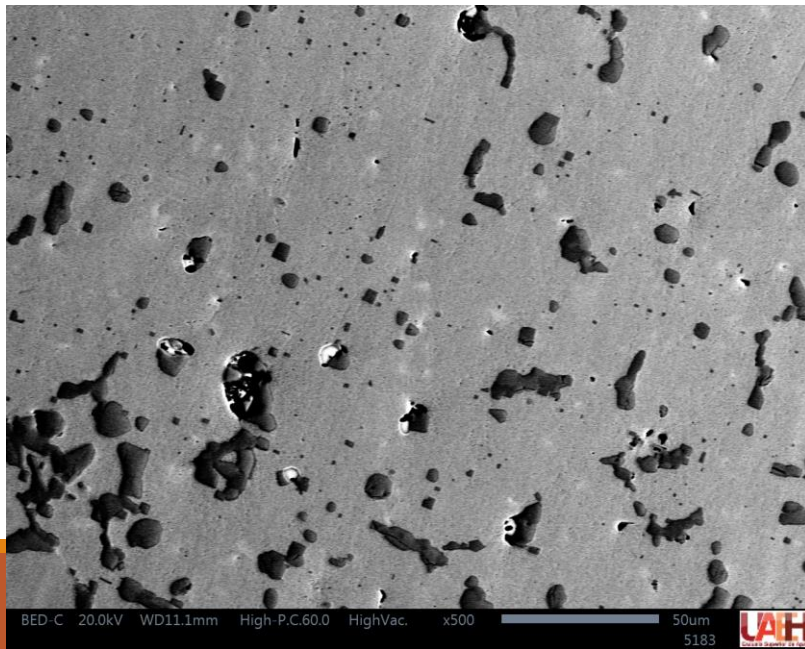


T4

Zona central

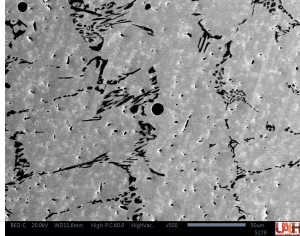
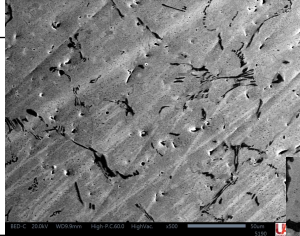
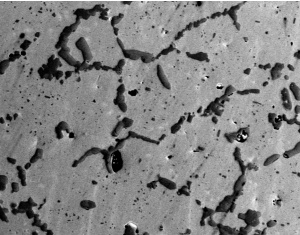
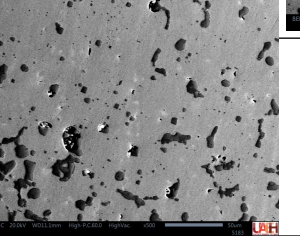


Zona superficial
1 mm





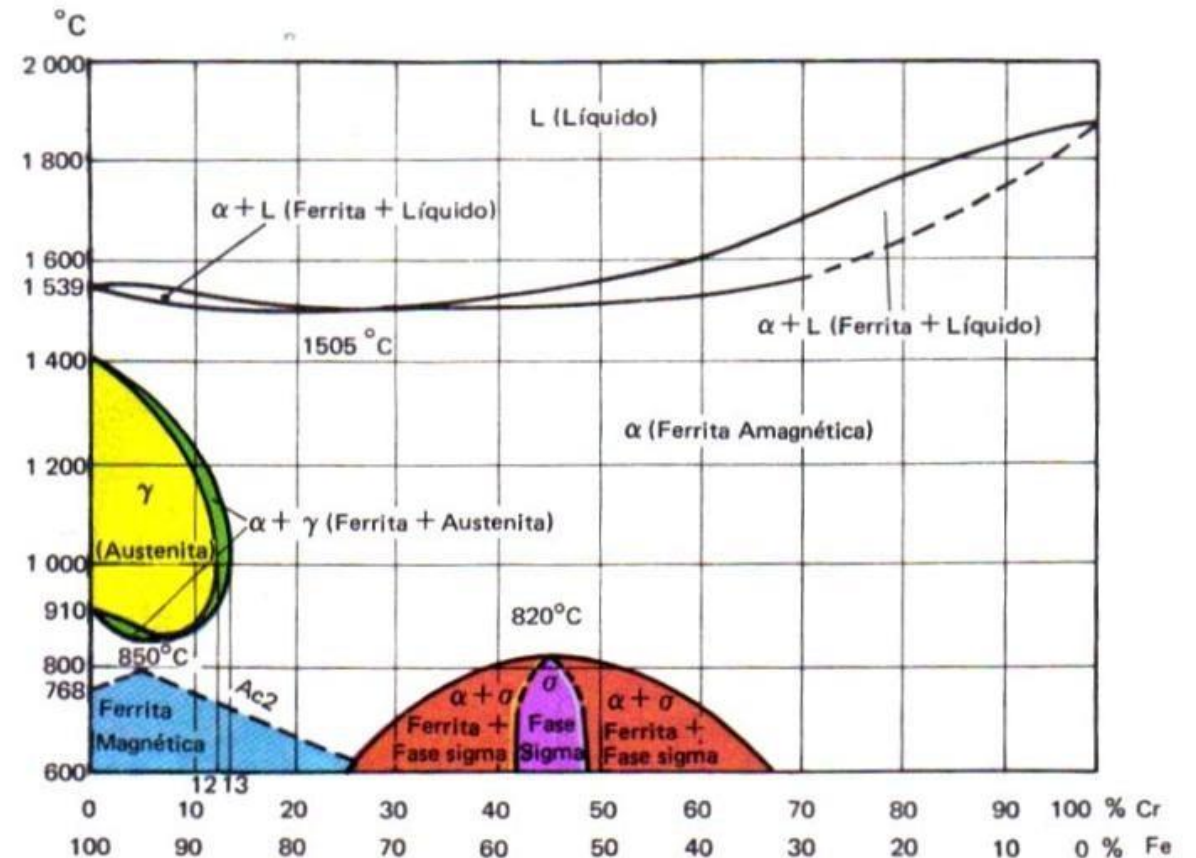
Resumen

ID	Descripción	Zona	Dureza HRV	Distancia entre planos	Porcentaje en peso (%W)								Microestructura
					Fe	Ni	Cr	C	Si	Mn	Mo	Al	Apariencia a 500x
T1	Material nuevo	Centro	213	0.824429	32.5	32	25.3	7.1	1.5	1	0.5	0.2	
		Superficie 1mm			N/A								
T3	Primer rectificada sin usar	Centro	282	0.8182922	33,3	31.9	26.2	5.6	1.9	0.8	0	0.1	
		Superficie 1mm	203		32.4	31.3	26.6	6.7	2	0.9	0.3		
T4	Pandeado 3 usado	Centro	195	0.6859739	31.7	30.6	26.7	7.8	2	1		0.1	
		Superficie 1mm	243		33.8	32.1	24.7	5.9	1.9	1	0.4	0.1	

Precipitados del acero Inoxidable

Diagrama Carbono-Cromo Hierro

Phase	Crystal structure	Lattice parameters, nm	Reported compositions	Comments
M ₂₃ C ₆	Face-centered cubic	a ₀ = 1.057–1.068	(Cr ₁₆ Fe ₃ Mo ₂)C ₆ (Cr ₁₇ Fe _{4.5} Mo _{1.5})C ₆ (Fe,Cr) ₂₃ C ₆	Most commonly observed carbide in austenitic stainless steels. Precipitates from 500–950 °C (930–1740 °F), fastest at 650–700 °C (1200–1290 °F)
M ₆ C	Face-centered cubic	a ₀ = 1.085–1.111	(Cr,Co,Mo,Ni) ₆ C (Fe ₃ Mo ₃)C Fe ₃ Nb ₃ C (Fe,Cr) ₃ Nb ₃ C	Observed in austenitic grades containing substantial molybdenum or niobium after long time exposure
M ₇ C ₃	Hexagonal	a ₀ = 1.398 c ₀ = 0.4523	Cr ₇ C ₃	Observed in martensitic grades
MC	Cubic	a ₀ = 0.430–0.470	TiC NbC	Observed in alloys with additions of titanium or niobium. Very stable carbide. Will usually contain some nitrogen
Sigma (σ)	Tetragonal	a ₀ = 0.8799–0.9188 c ₀ = 0.4544–0.4599	FeCr FeMo Fe(Cr,Mo) (Fe,Ni) _x (Cr,Mo) _y	Formation from δ-ferrite is much more rapid than from austenite. Potent embrittler below 595 °C (1105 °F). Forms with long time exposure from 650–900 °C (1200–1650 °F)
Chi (χ)	Body-centered cubic: (α-Mn structure)	a ₀ = 0.8862–0.892	Fe ₃₆ Cr ₁₂ Mo ₁₀ (FeNi) ₃₆ Cr ₁₈ Mo ₄ M ₁₈ C	Observed in alloys containing substantial molybdenum. Chi precipitates with exposure to 730–1010 °C (1345–1850 °F) (varies with alloy composition).
Laves	Hexagonal	a ₀ = 0.470–	Fe ₂ Mo	Forms in austenitic alloys with substantial





7.6 Referencia

Thermal treatments are listed in order of decreasing preference.

A: Anneal at 1065 to 1120 °C (1950 to 2050 °F) and then slow cool.

B: Stress relieve at 900 °C (1650 °F) and then slow cool.

C: Anneal at 1065 to 1120 °C (1950 to 2050 °F) and then quench or cool rapidly.

D: Stress relieve at 900 °C (1650 °F) and then quench or cool rapidly.

E: Stress relieve at 480 to 650 °C (900 to 1200 °F) and then slow cool.

F: Stress relieve at below 480 °C (900 °F) and then slow cool.

G: Stress relieve at 205 to 480 °C (400 to 900 °F) and then slow cool (usual time, 4 h per inch of section).

- *Heating at 815 to 925 °C (1500 to 1700 °F):* The coalescence of chromium carbide precipitates or σ phase will occur, resulting in a form less harmful to corrosion resistance or mechanical properties
- *Heating at 955 to 1120 °C (1750 to 2050 °F):* This annealing treatment causes all grain-boundary chromium carbide precipitates to redissolve and transforms σ back to ferrite, as well as fully softening the steel. Long heating times (>1 h) may even dissolve some of the ferrite present and further reduce the probability of σ reforming upon slow cooling

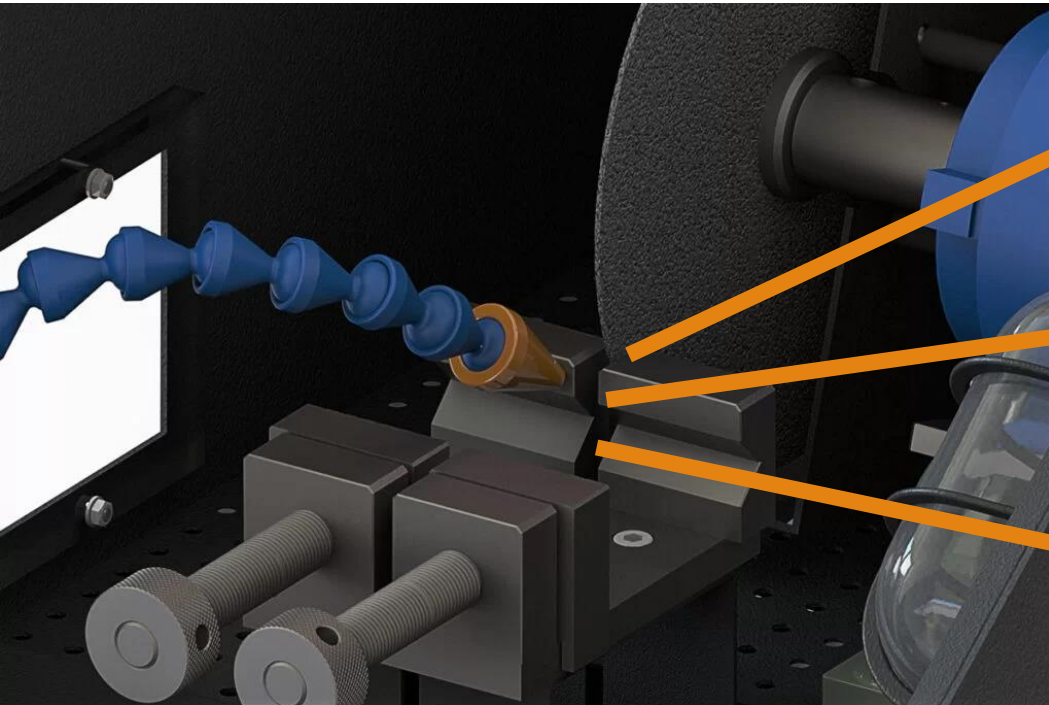
Application or desired characteristics	Extra-low-carbon grades, such as 304L and 316L	Suggested thermal treatment ^(a)	
		Stabilized grades, such as 318, 321, and 347	Unstabilized grades, such as 304 and 316
Severe stress corrosion	A, B	B, A	^(b)
Moderate stress corrosion	A, B, C	B, A, C	^(b)
Mild stress corrosion	A, B, C, E, F	B, A, C, E, F	C, F
Remove peak stresses only	F	F	F
No stress corrosion	None required	None required	None required
Intergranular corrosion	A, C ^(c)	A, C, B ^(c)	C
Stress relief after severe forming	A, C	A, C	C
Relief between forming operations	A, B, C	B, A, C	^(d)
Structural soundness ^(e)	A, C, B	A, C, B	C



8.0 Diseño experimental



8.1 Muestreo





8.2 Tratamiento Térmico

Cálculos para permanencia en horno:

$$t = \frac{L^2}{\alpha} \quad \alpha = \frac{k}{\rho * C_p}$$

Datos:

t = Tiempo de calentamiento homogéneo (segundos)

L = Distancia al centro del cubo (mts)

α = Difusividad térmica (m^2/s)

k = Conductividad térmica ($W/m \cdot K$) = 20 $W/m \cdot K$

ρ = Densidad (kg/m^3) = 7900 kg/m^3

C_p = Calor específico a presión constante ($J/kg \cdot K$) = 600 $J/kg \cdot K$

$$\alpha = \frac{20 \text{ W/m} \cdot \text{K}}{7900 \text{ kg/m}^3 * 600 \text{ J/kg} \cdot \text{K}}$$

$$\alpha = 4.2 \times 10^{-6} \text{ m}^2/\text{s}$$

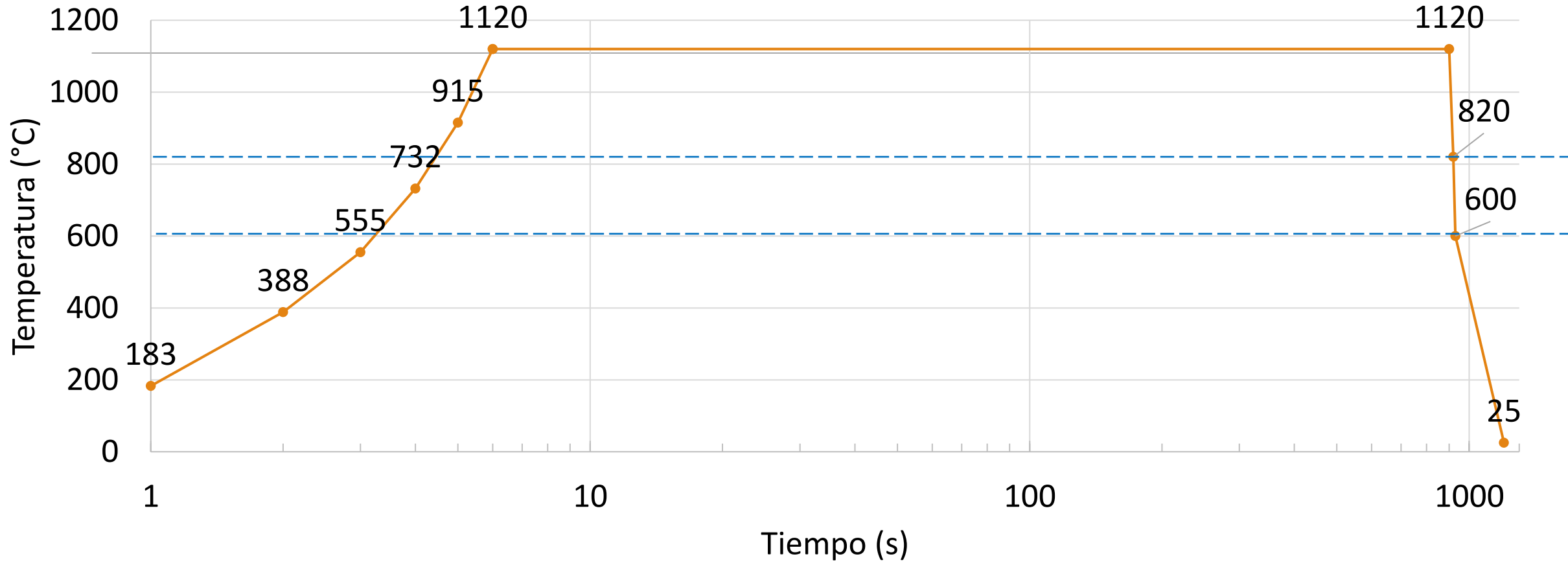
$$t = \frac{(0.005 \text{ mts})^2}{4.2 \times 10^{-6} \text{ m}^2/\text{s}}$$

$$t = 5.95 \text{ s}$$



8.2 Tratamiento Térmico

Ciclo térmico



8.2.2- Tratamiento Térmico EQUIPO

Horno de cámara LHTC
MAX. 1550°C 1.5 L



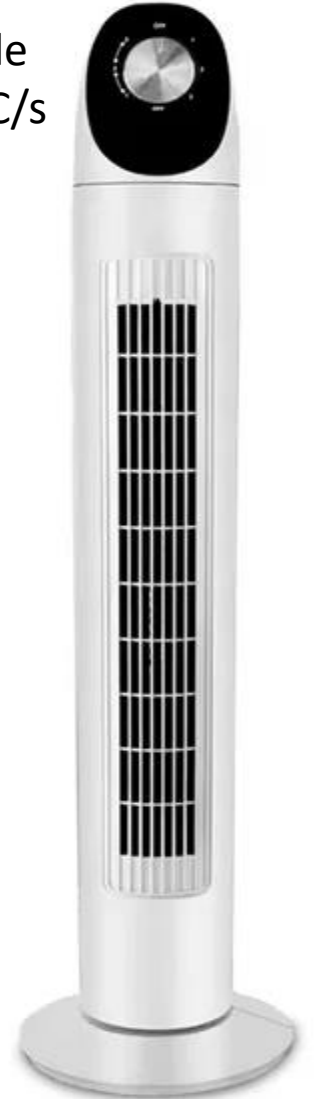
Recipiente de agua 10 Lts
25°C temp. Velocidad de
enfriamiento 500 – 1000 °C/s



Recipiente de aceite mineral 5
Lts
25°C temp. Velocidad de
enfriamiento 150 – 300 °C/s

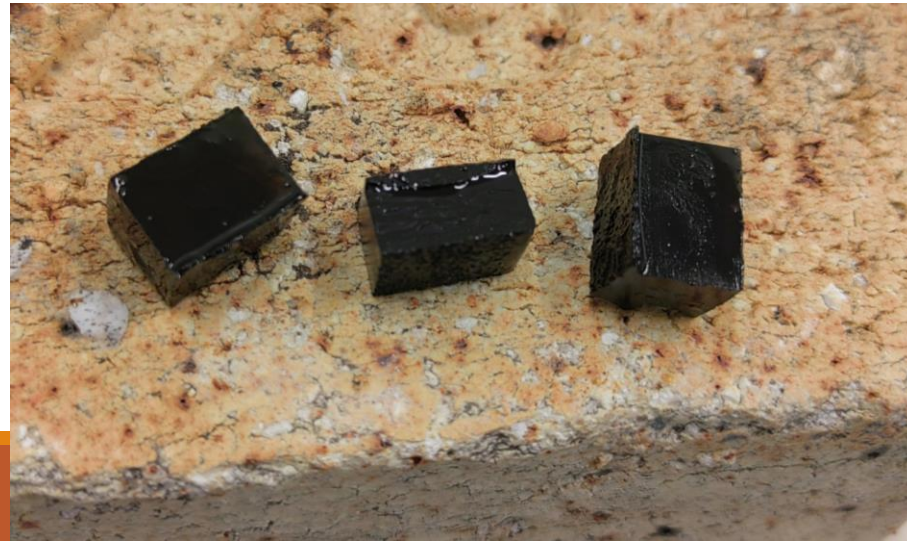
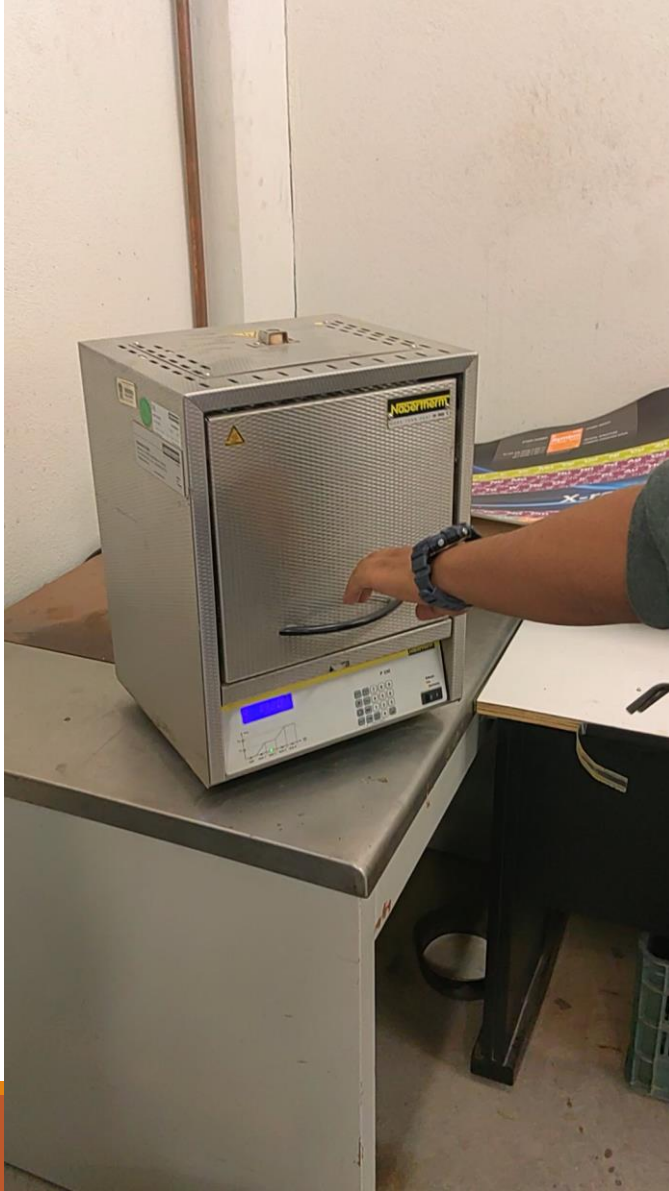


Ventilador vertical
28°C temp. Velocidad de
enfriamiento 10 – 50 °C/s





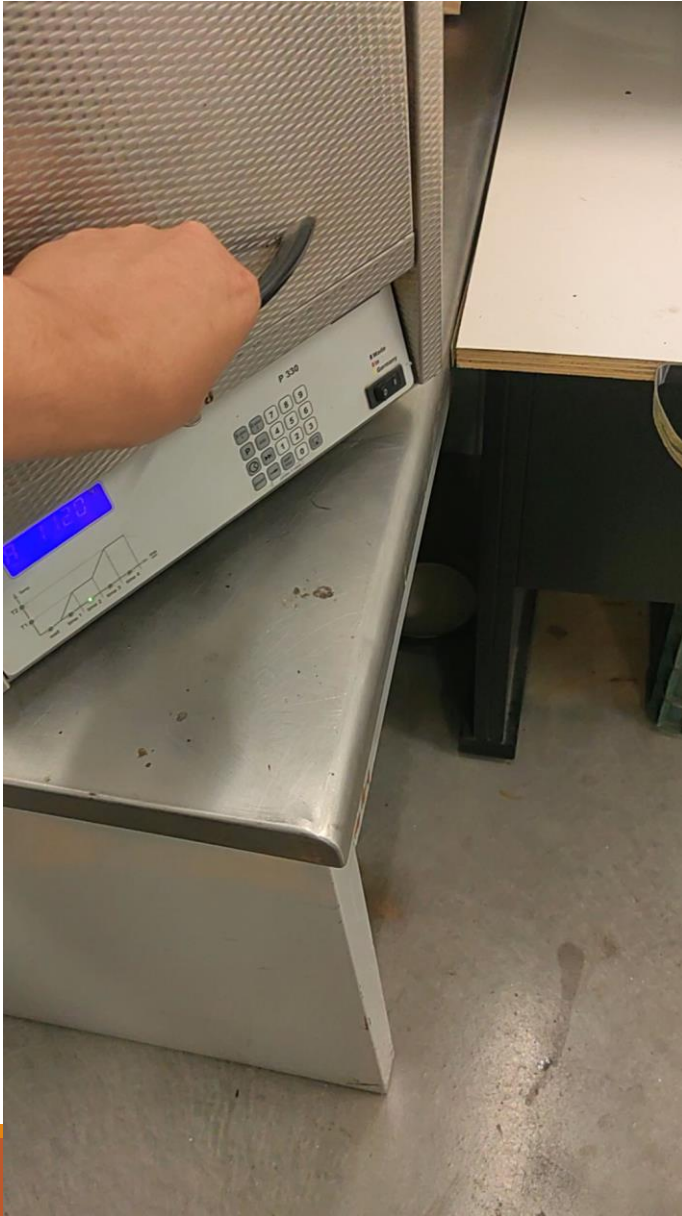
8.2.3 (A) Enfriamiento en Agua



Tiempo de enfriamiento observado 3.5 Segundos



8.2.4 (B) Aceite



Tiempo de enfriamiento
observado 8.5 Segundos



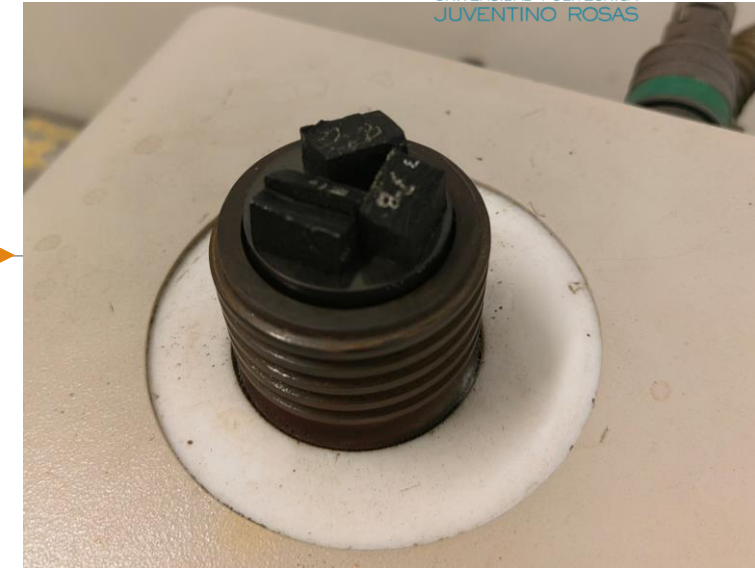
8.2.6 (C) Aire



Tiempo de enfriamiento
observado 38 Segundos

1.- Encapsulado

Montadora LECO 0R32,
LUCITE POWDER. 150°C
4000 PSI



2.- Desbaste

Lijas #320, #600,
#1000 y #1200



3.- Pulido

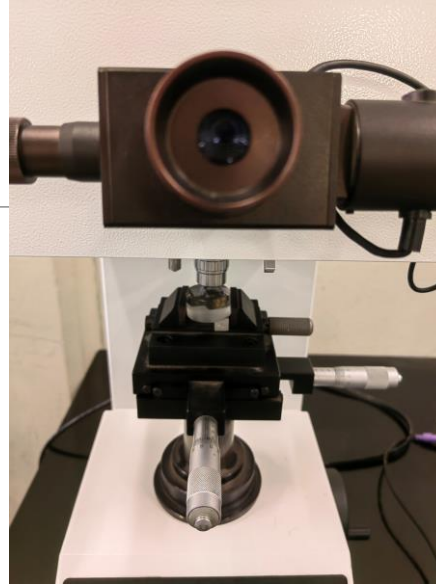
Alumina 1 μ



4.- Ataque Químico

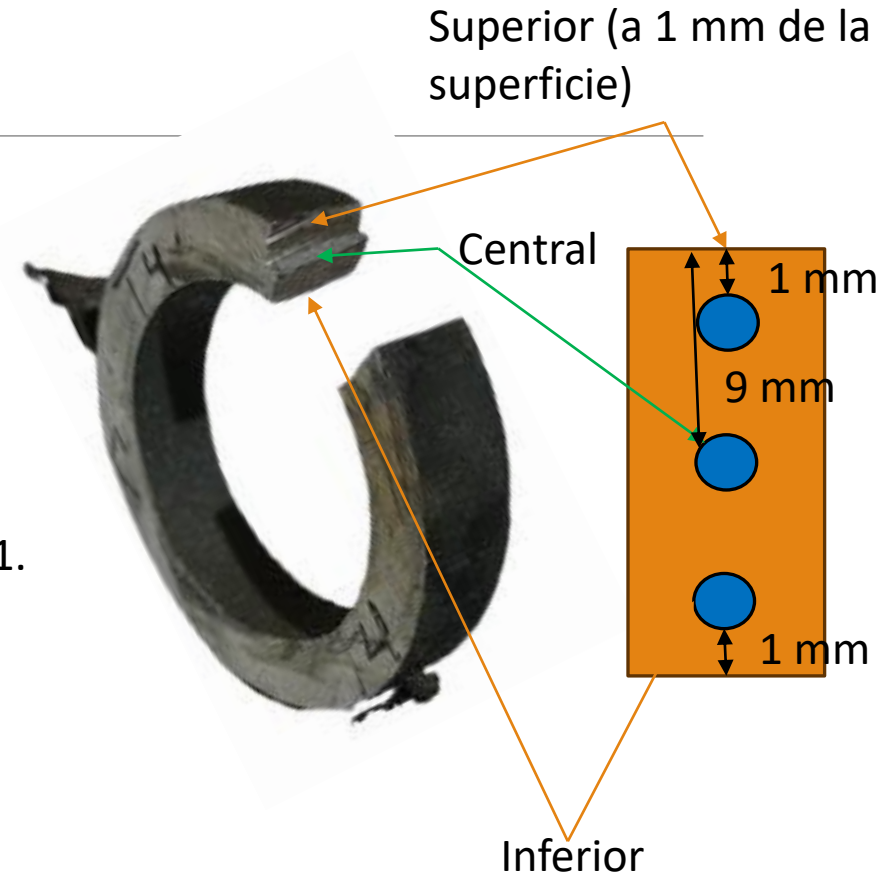


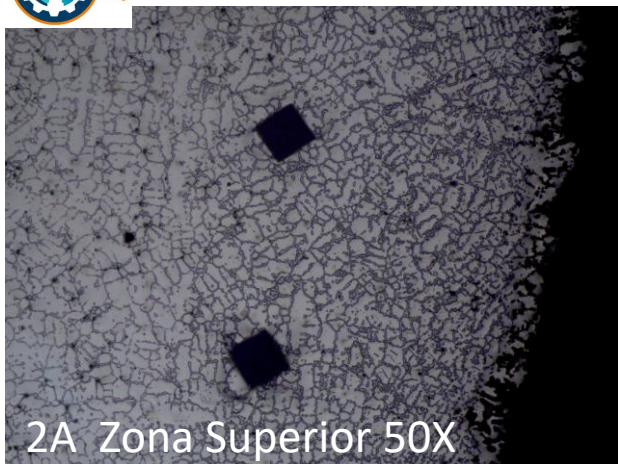
5.- Inspección de Dureza Vickers



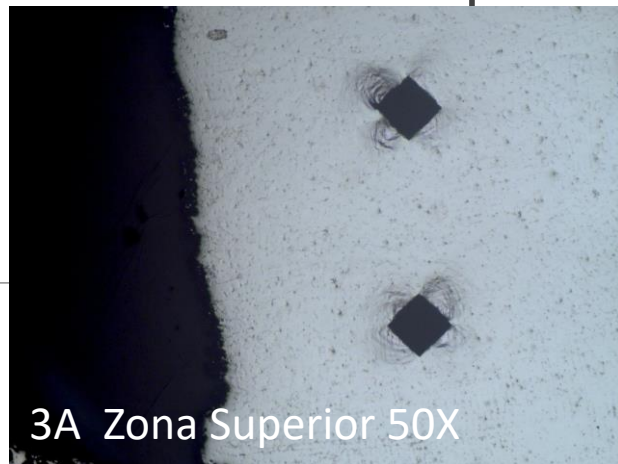
Microscopio óptico OLYMPUS GX-41.
50X, 100X. 500X

6.- Inspección Microestructural

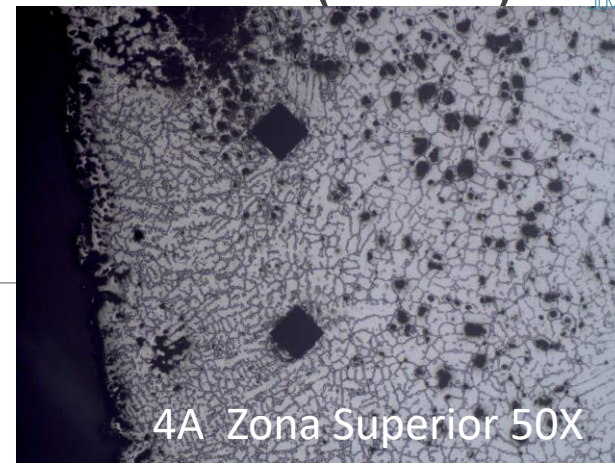




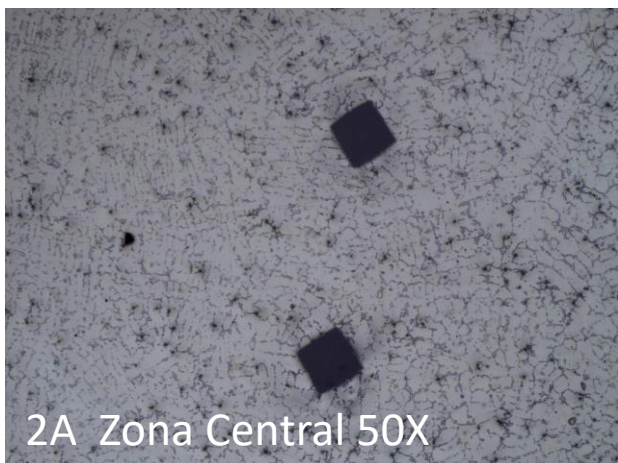
2A Zona Superior 50X



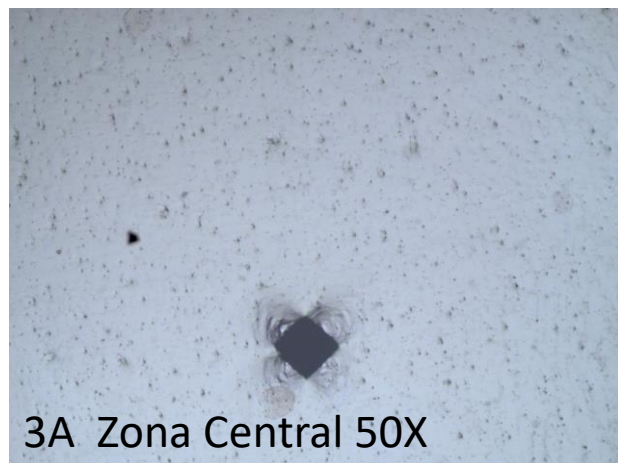
3A Zona Superior 50X



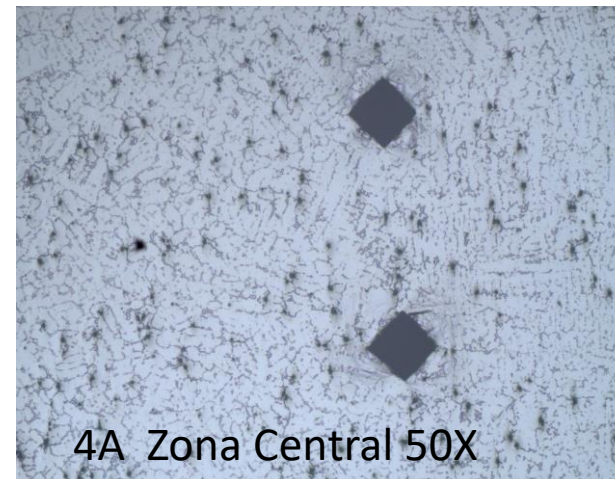
4A Zona Superior 50X



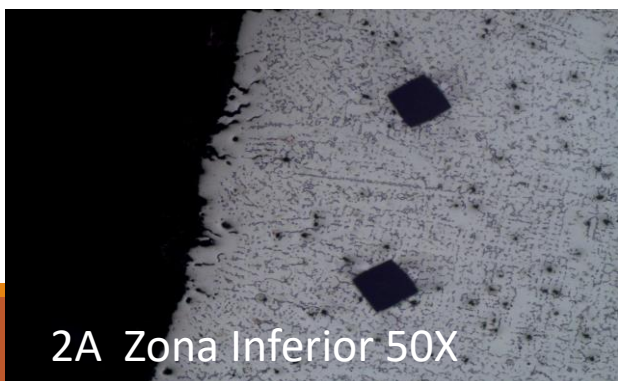
2A Zona Central 50X



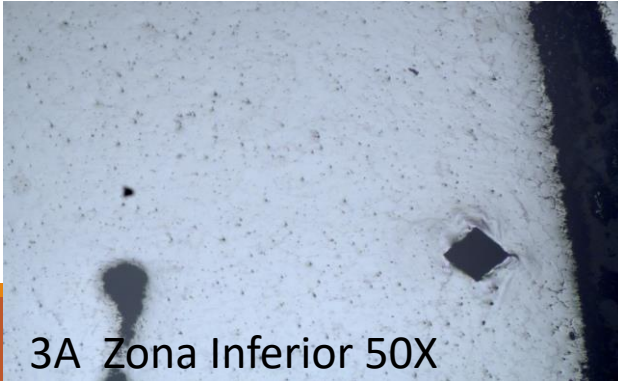
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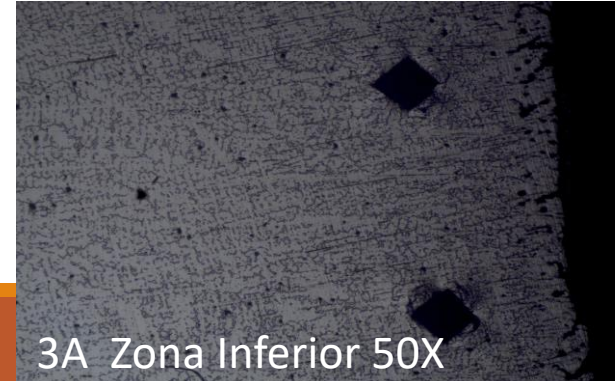
4A Zona Central 50X



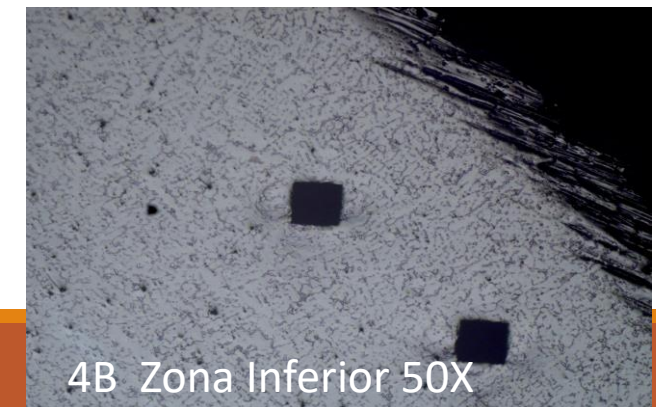
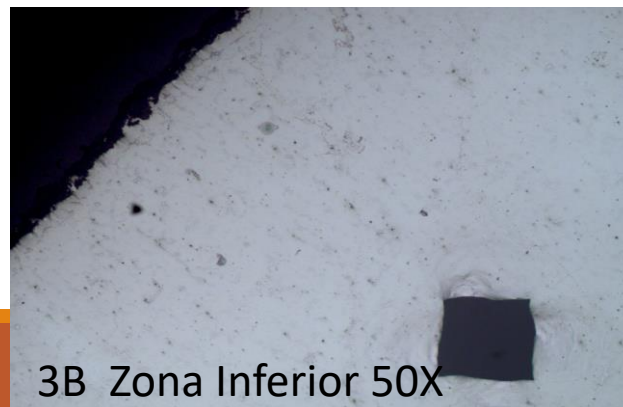
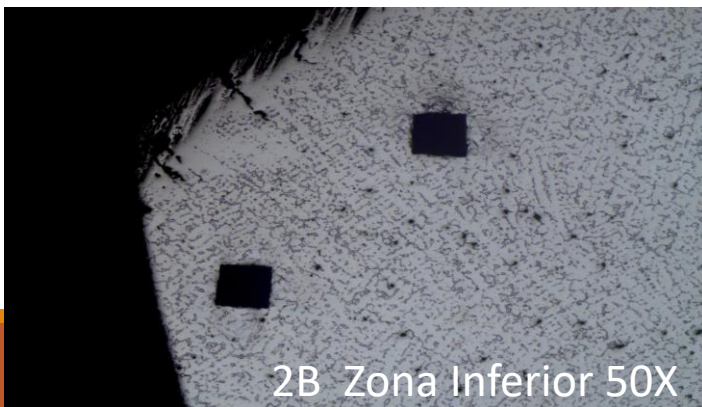
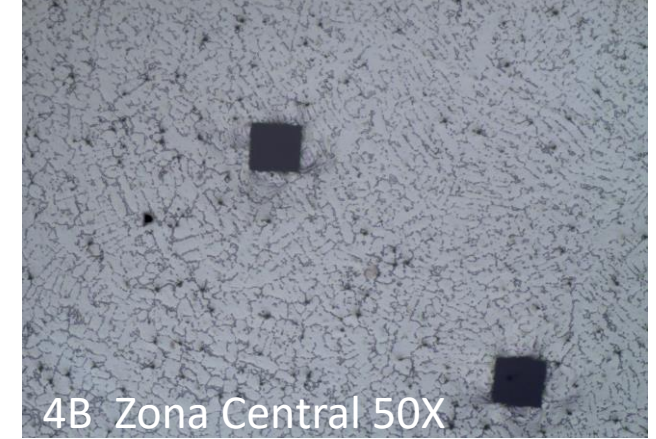
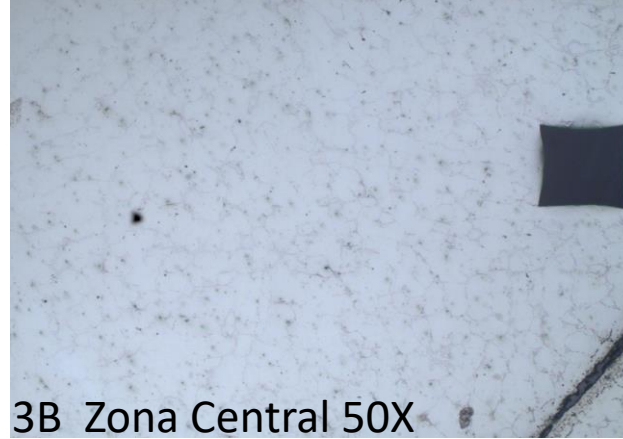
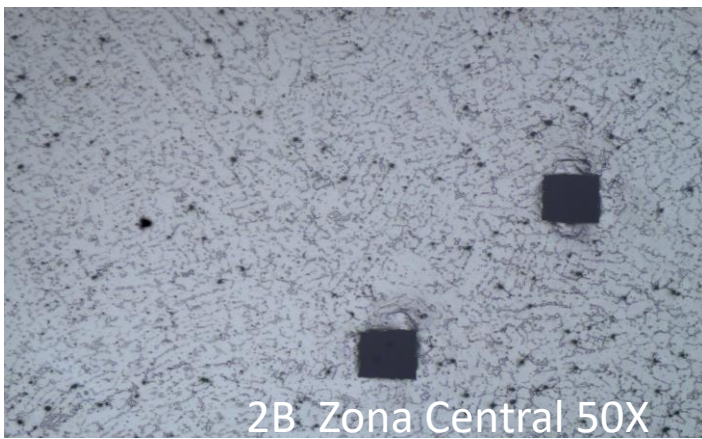
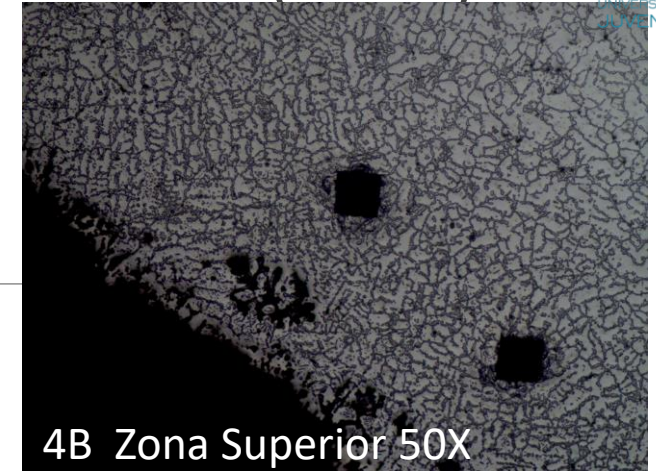
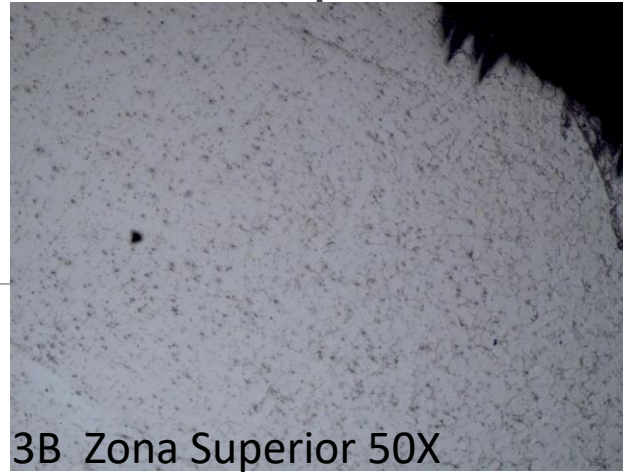
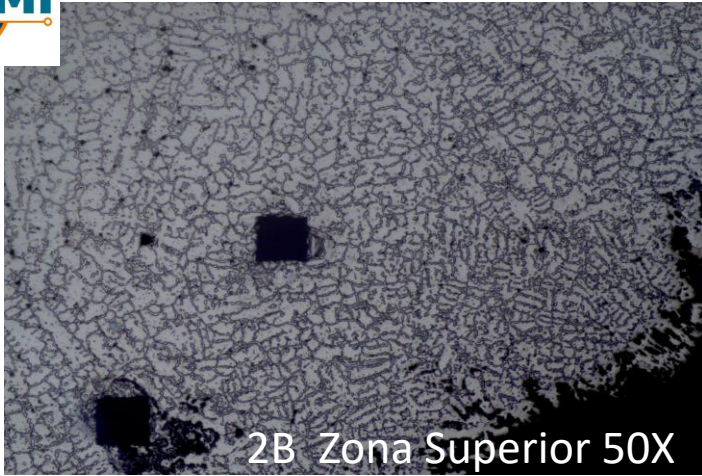
2A Zona Inferior 50X



3A Zona Inferior 50X



3A Zona Inferior 50X

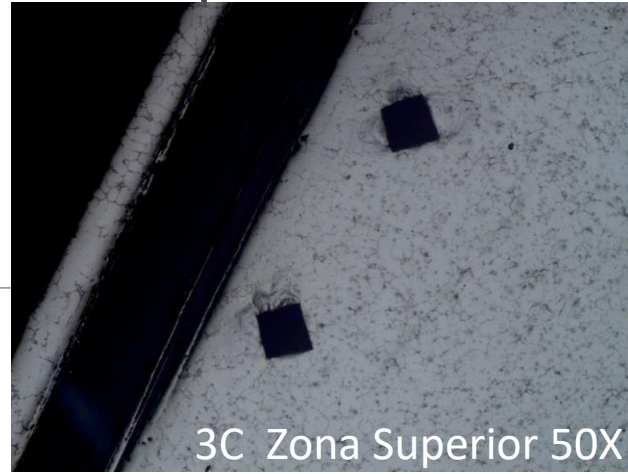




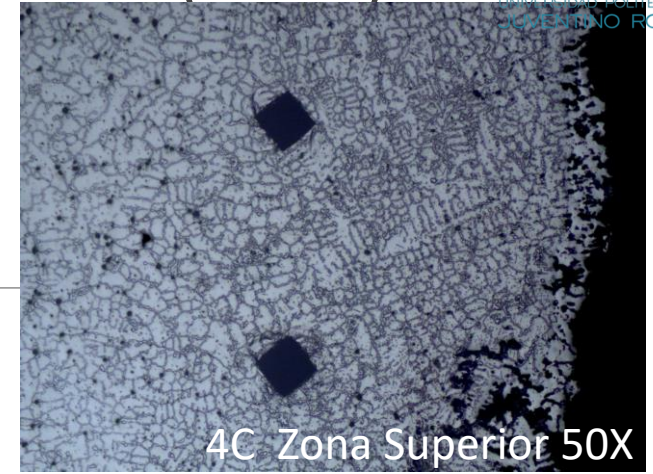
9.3 Resultados medio C Inspección de Dureza (HRV)



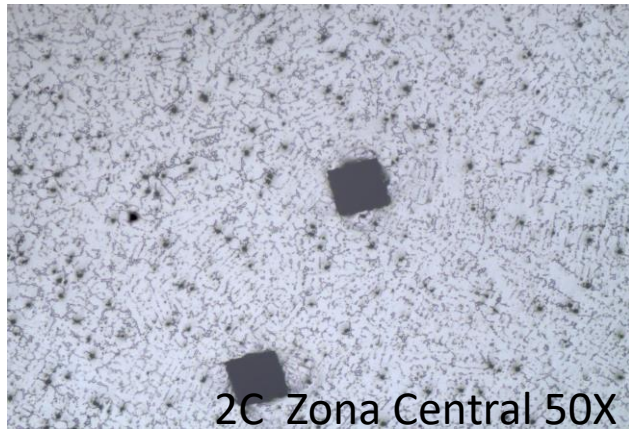
2C Zona Superior 50X



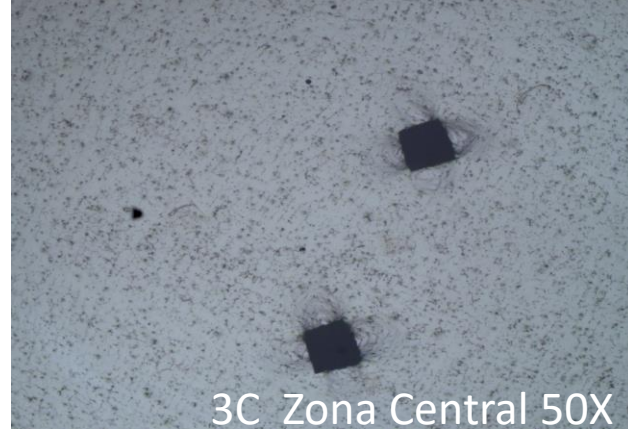
3C Zona Superior 50X



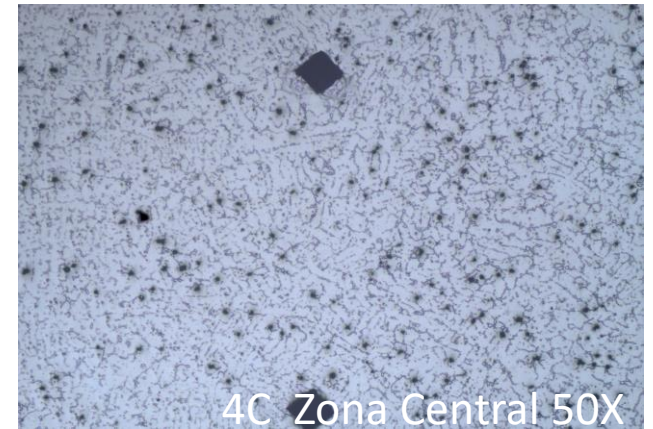
4C Zona Superior 50X



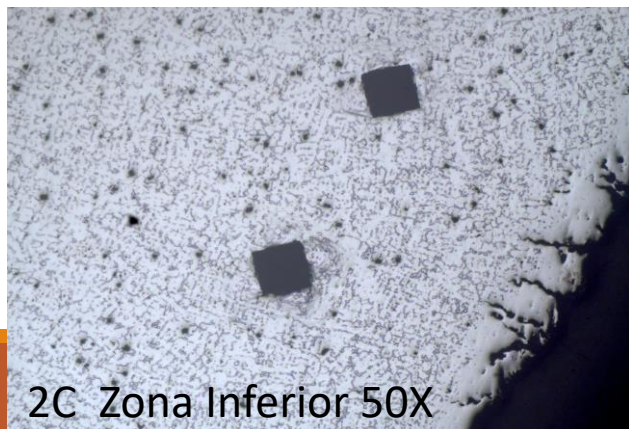
2C Zona Central 50X



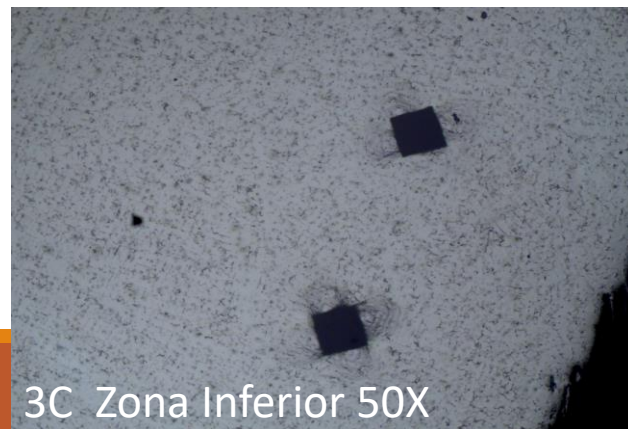
3C Zona Central 50X



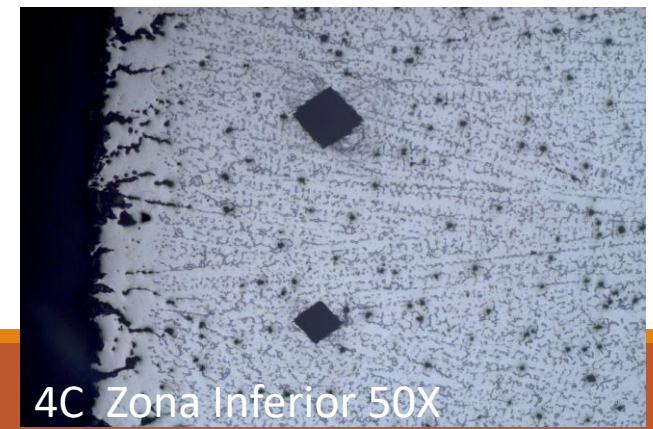
4C Zona Central 50X



2C Zona Inferior 50X



3C Zona Inferior 50X

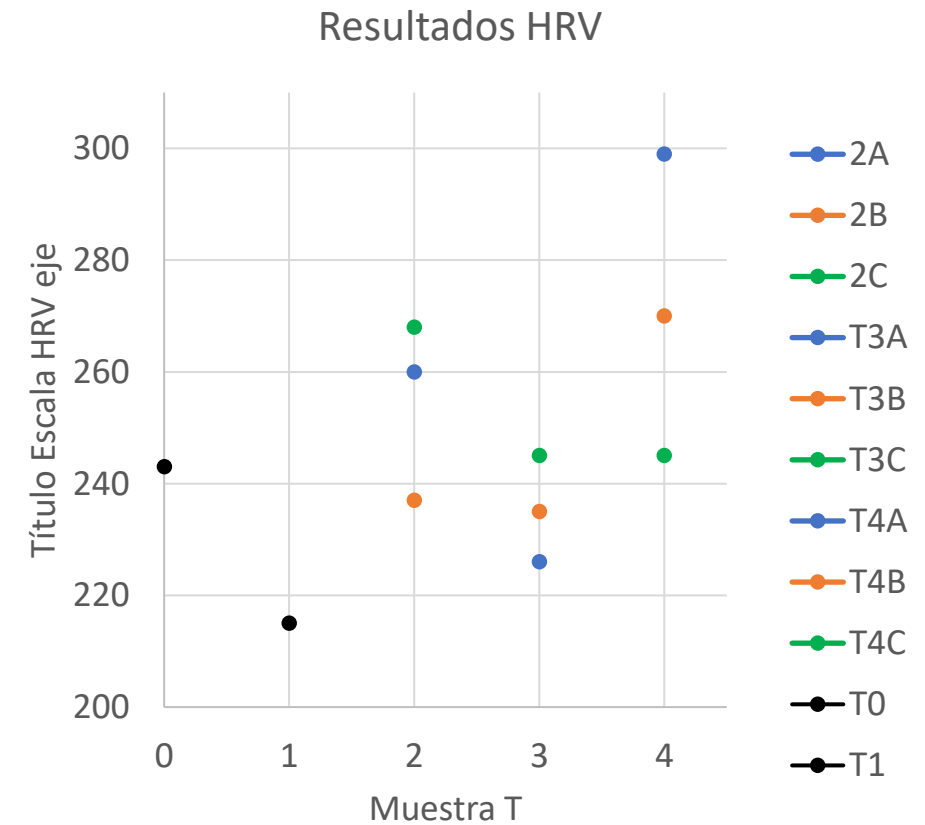


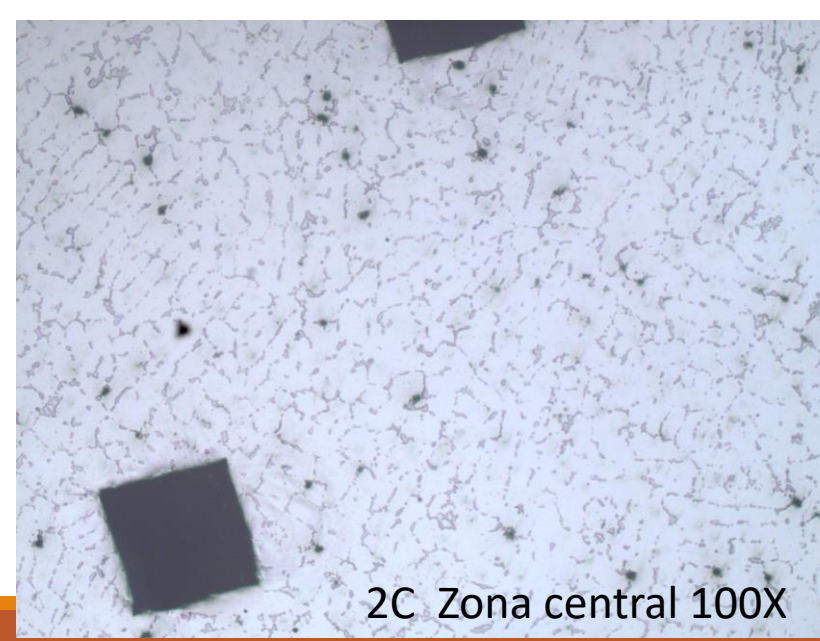
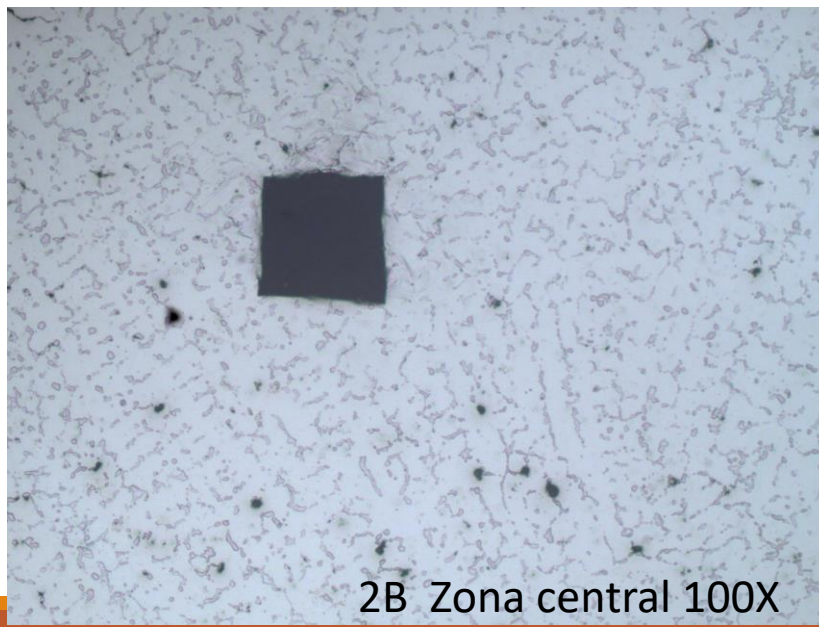
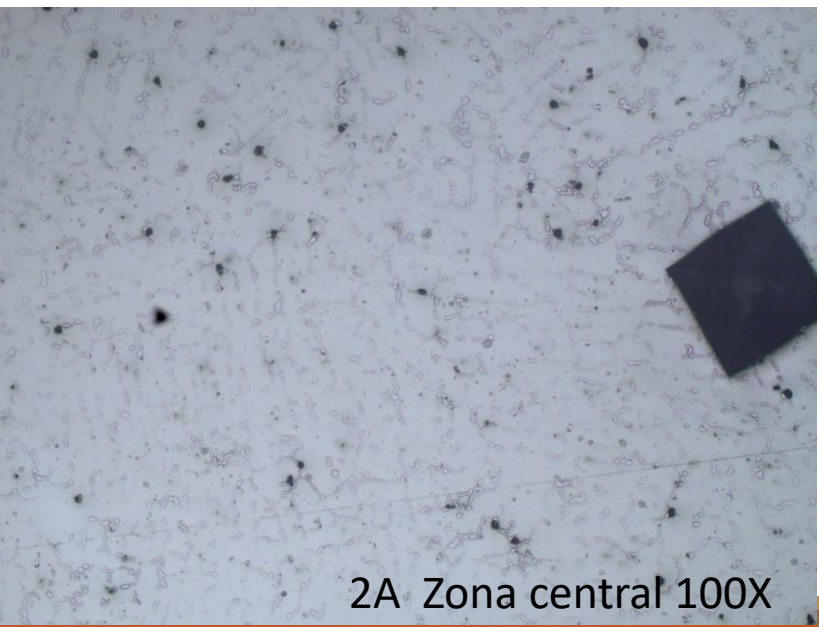
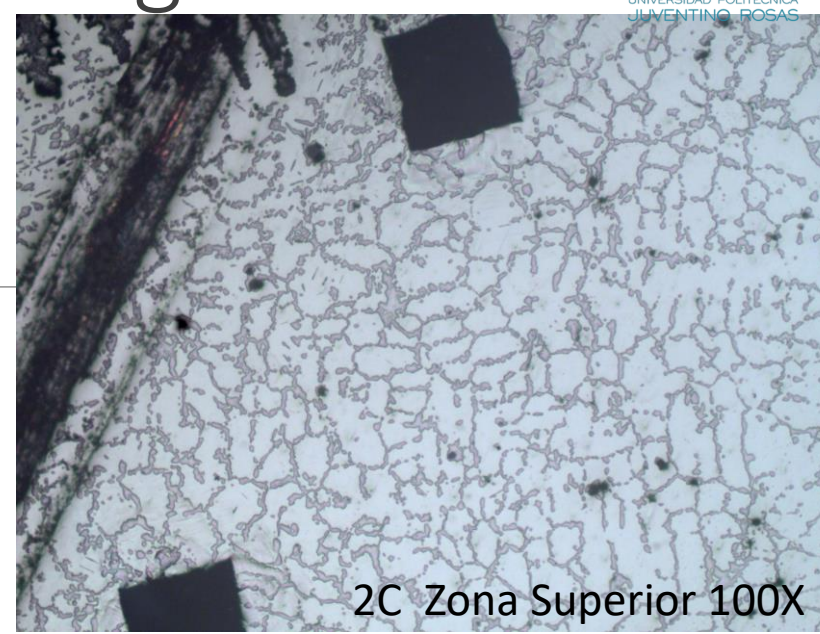
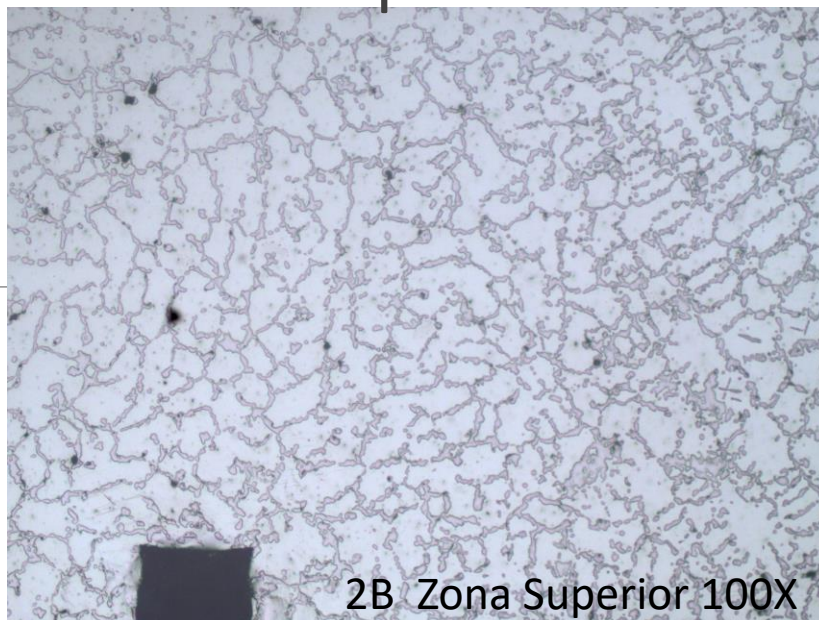
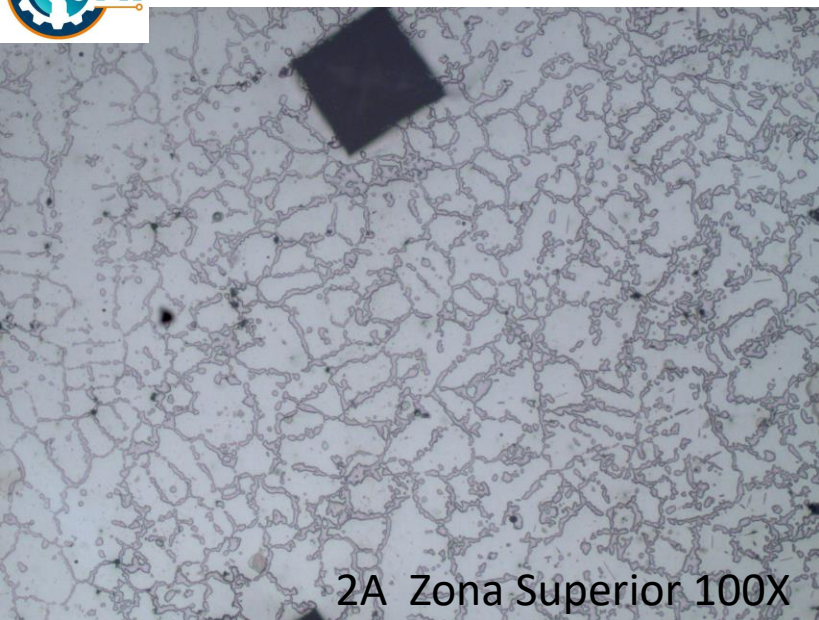
4C Zona Inferior 50X

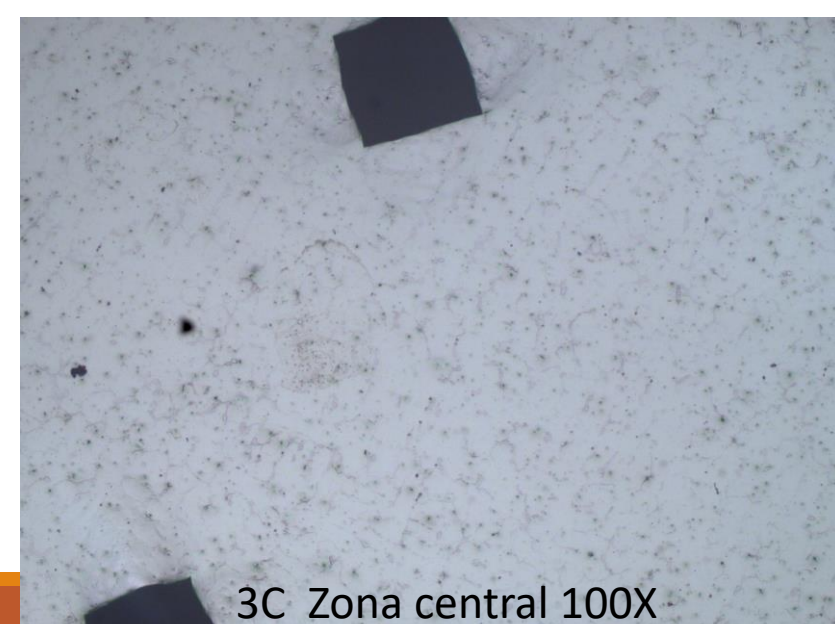
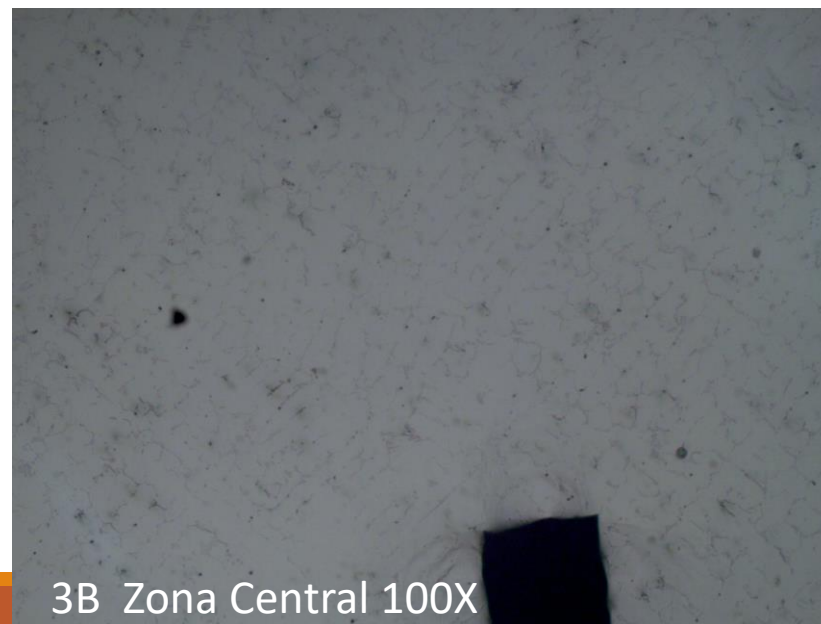
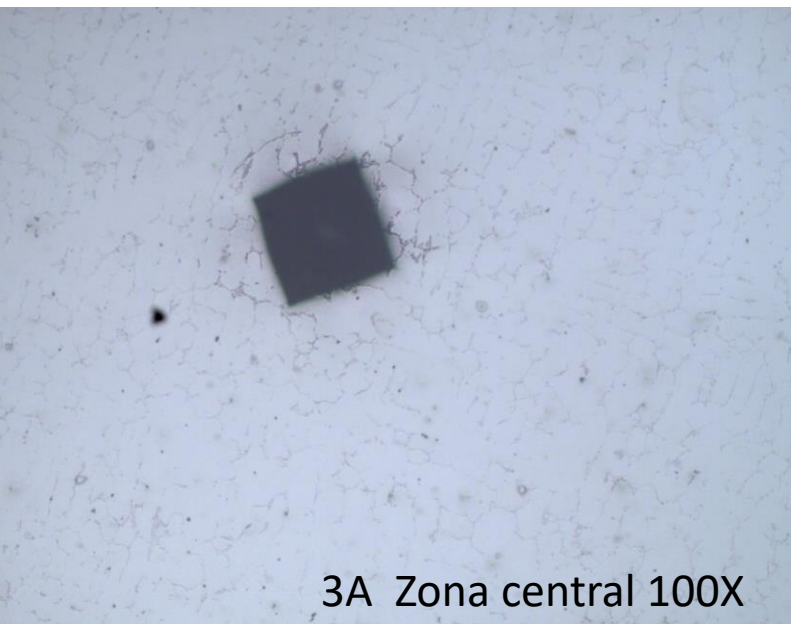
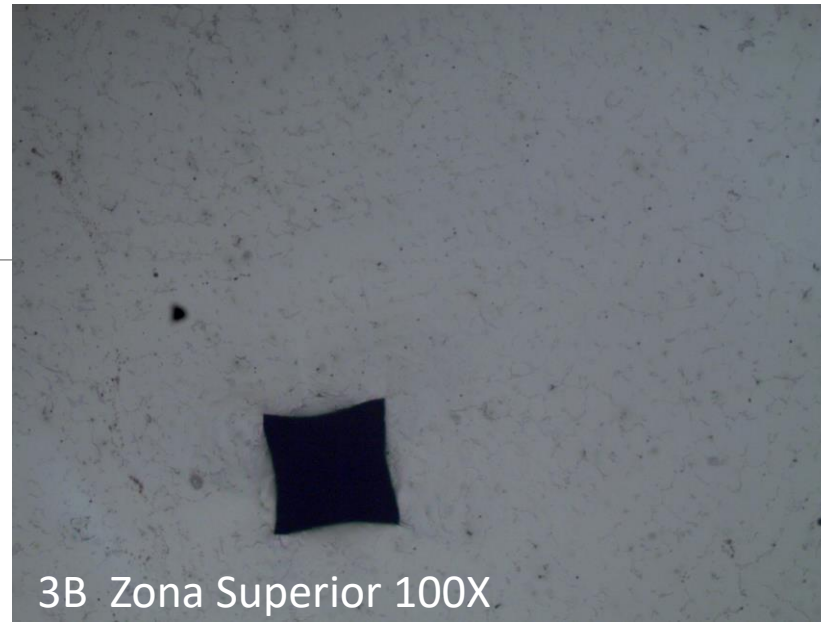
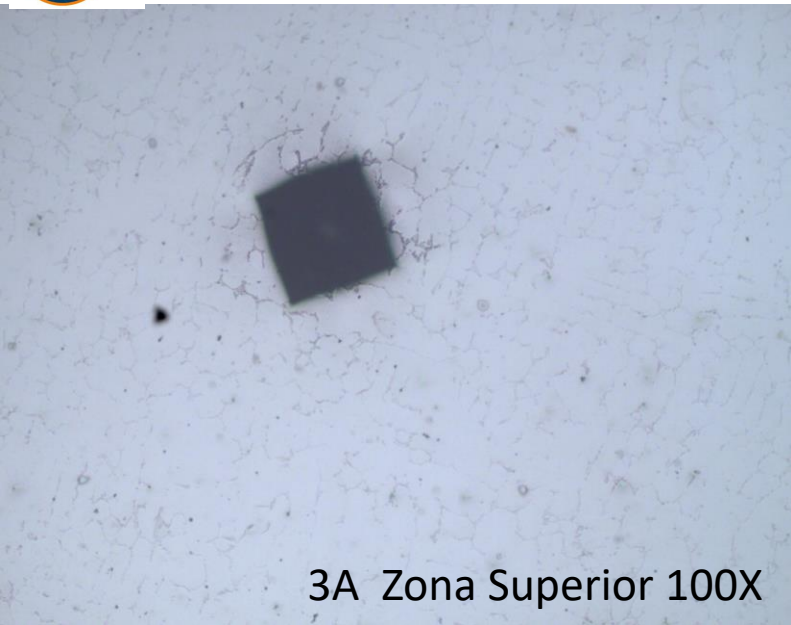


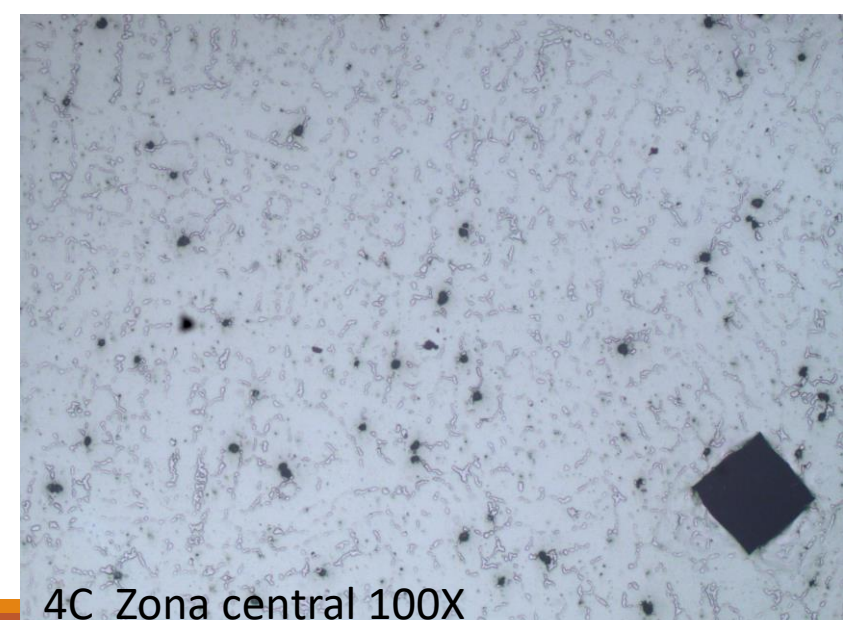
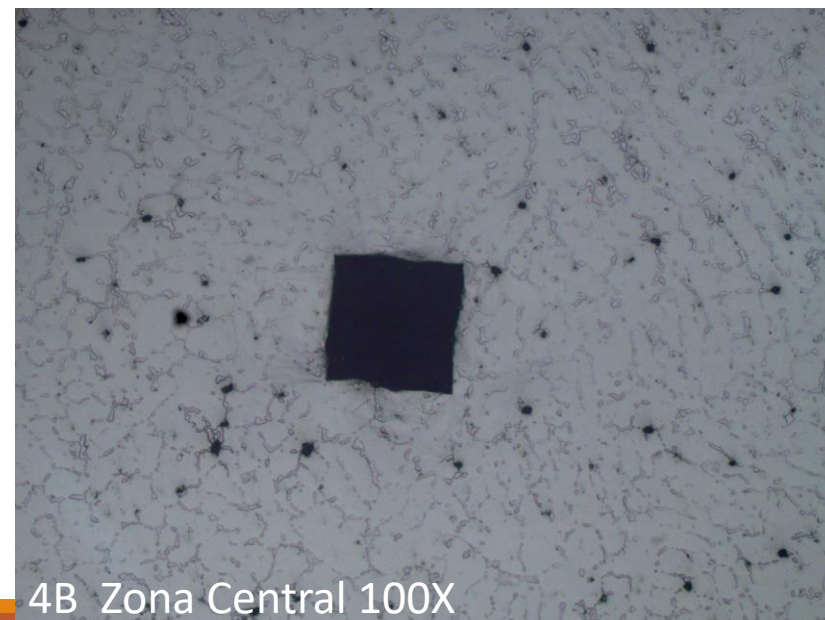
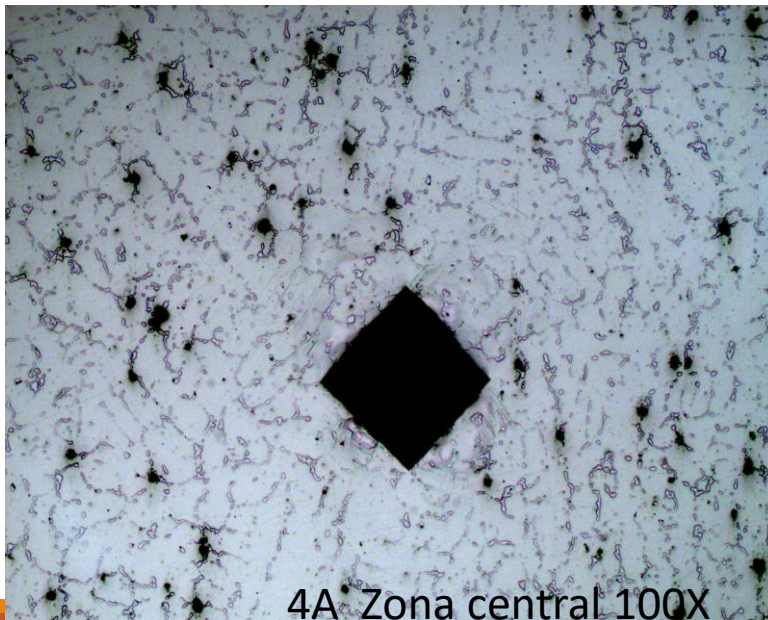
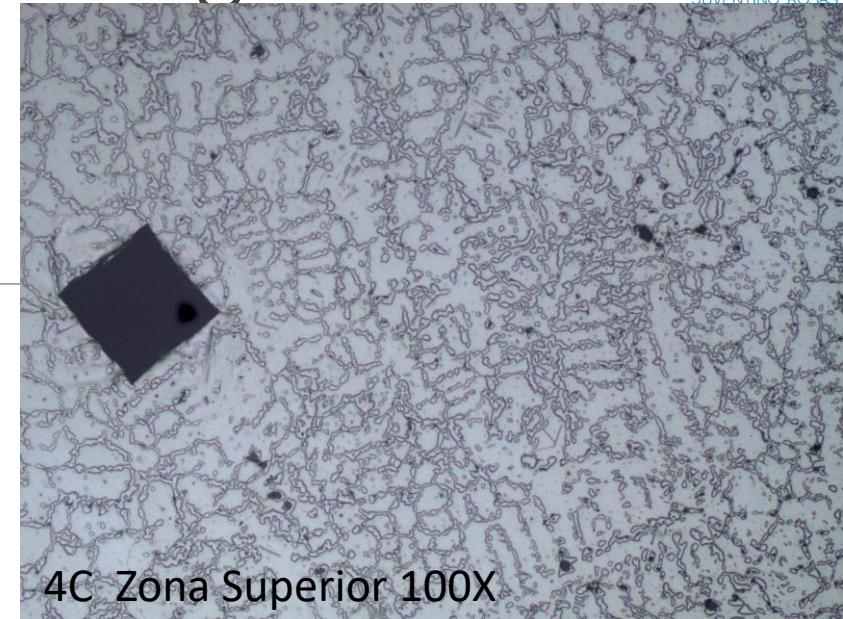
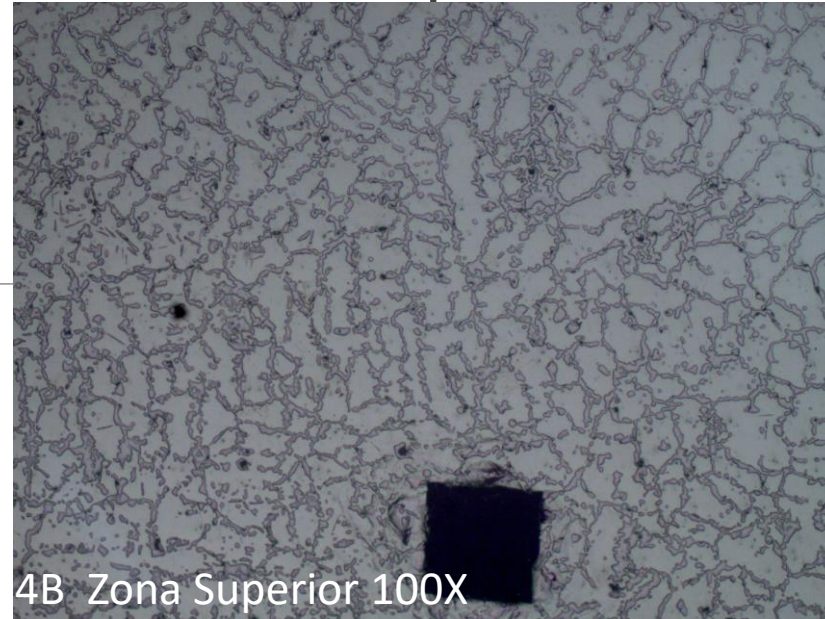
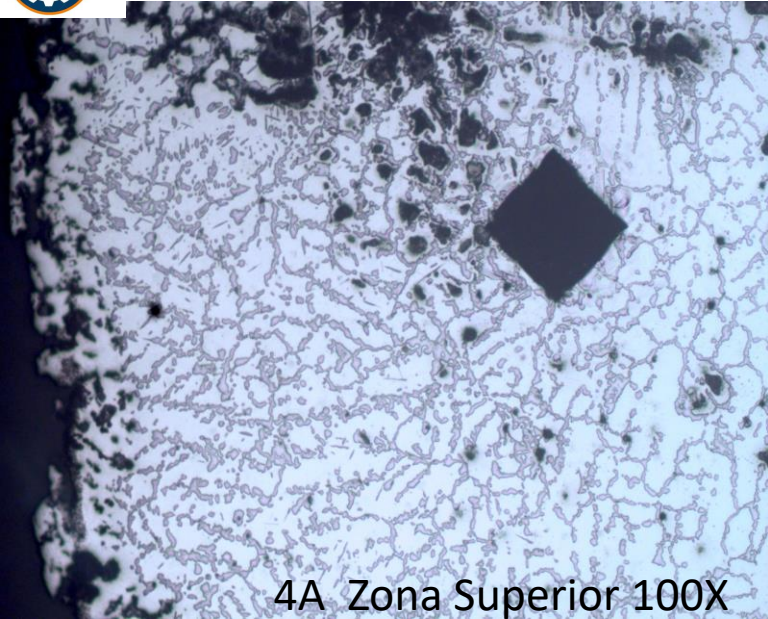
Resultados de Dureza Vickers

ID	TEST	Dureza zona superior		Dureza Central		Dureza Inferior	
A	T2	260	261	208	211	219	230
	T3	226	244	241	242	236	216
	T4	299	285	212	208	215	235
B	T2	237	246	200	200	222	222
	T3	235	221	236	236	245	240
	T4	270	270	205	201	215	217
C	T2	268	252	195	188	206	204
	T3	245	233	246	242	230	224
	T4	245	257	222	224	217	224
N/A	T0 (T4 sin TT)	243	238	196	195	210	115
	T1	215	206	212	202	204	202











10. Conclusión

1.- El software Orgin Pro 8 suavizó el espectro y pudo ser identificado por el programa MATCH 2 con mayor facilidad, a diferencia del análisis sin suavizado.

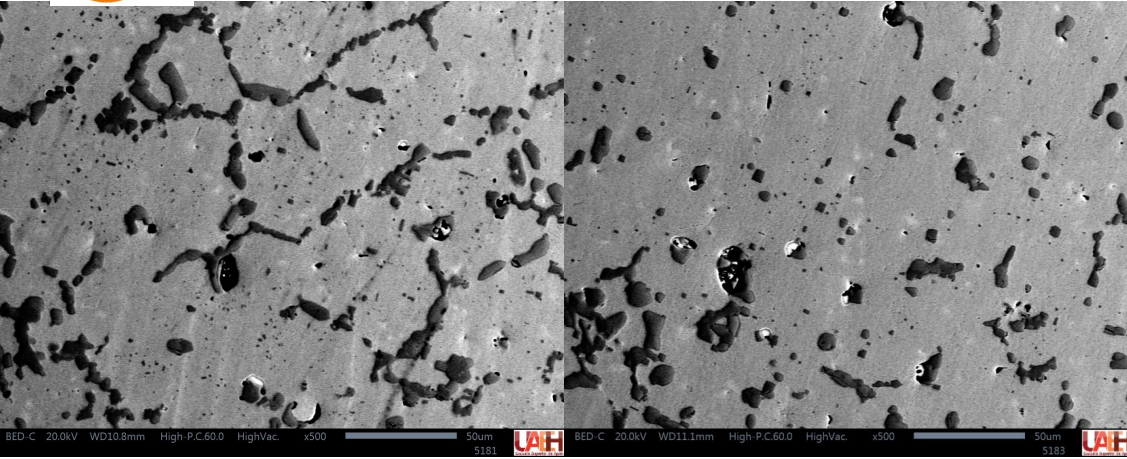
2.- La propuesta de tratamiento térmico abarca la posibilidad disminuir las tensiones internas y la dilución de carburos de cromo. Se necesita confirmar con una solución reveladora de fase sigma para determinar las mejorías.

3.- Para la el análisis de dureza en agua, T4 muestra la mayor dureza en la zona superior. El enfriamiento rápido puede inducir tensiones internas y microestructuras no deseadas.

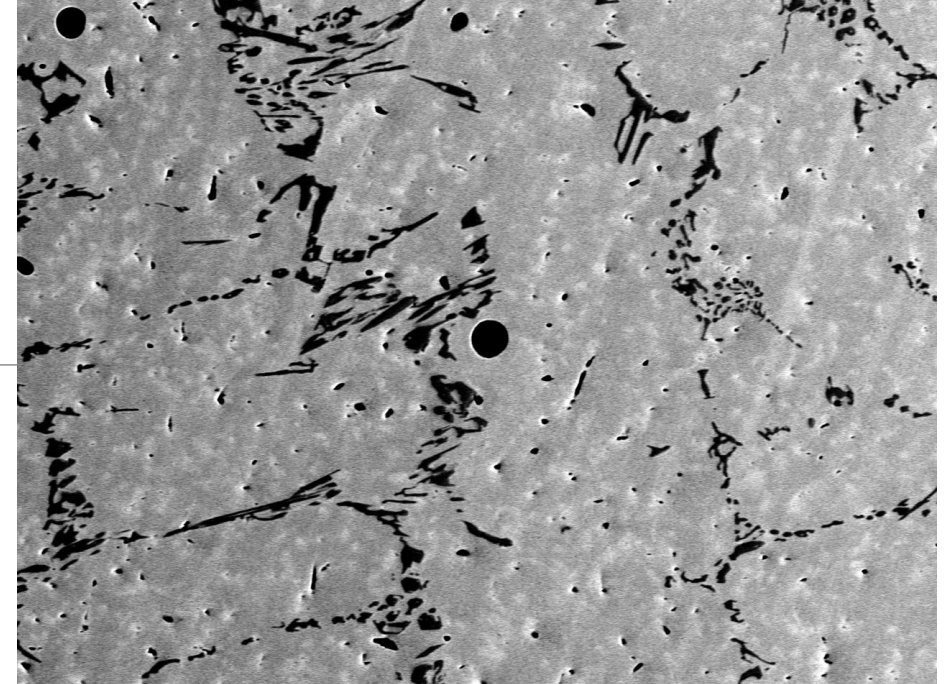
En aceite es más consistente y balanceado en comparación con agua. Las zonas centrales tienden a tener durezas ligeramente menores esto da buen equilibrio entre enfriamiento rápido y riesgo de deformación/tensión.

Para el aire forzado da las durezas más homogéneas entre zonas, aunque ligeramente menores. T2, la zona central muestra la menor dureza de toda la tabla (188). Probablemente mejor opción si se desea minimizar distorsiones mecánicas sin comprometer mucho la dureza.

4.- Para la microestructura se obtuvo lo siguiente:



T4 Condición antes del TT Zona Superior 500X



Condición de rodillo Original Zona Superior 500X



T4 Enfriamiento en agua Zona Superior 500X



T4 Enfriamiento en aceite Zona Superior 500X



11. -Bibliografía

1. Vigitec (2021) "MANUAL SOBRE ACEROS INOXIDABLES", manual técnico 1.
2. Copley, S. M. (1991a). *ASM Handbook Volume 04 - Heat Treating*. ASM INTERNATIONAL.
3. Copley, S. M. (1991b). *ASM Handbook Volume 09 - Metallography And Microstructures*. ASM INTERNATIONAL.
4. (S/f). Thomasnet.com. Recuperado el 17 de agosto de 2024, de <https://www.thomasnet.com/compsearch.html?what=Metal+Hot+Stamping+press&cov=NA&which=comp>



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