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Estudo de tratamento térmico de austêmpera para de microestrutura bainítica isenta de carbonetos (CFB).

Felipe Moreno Siqueira Borges de Carvalho

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Estudo de Tratamento Térmico de Austêmpera para de Microestrutura Bainítica Isenta de Carbonetos (CFB)

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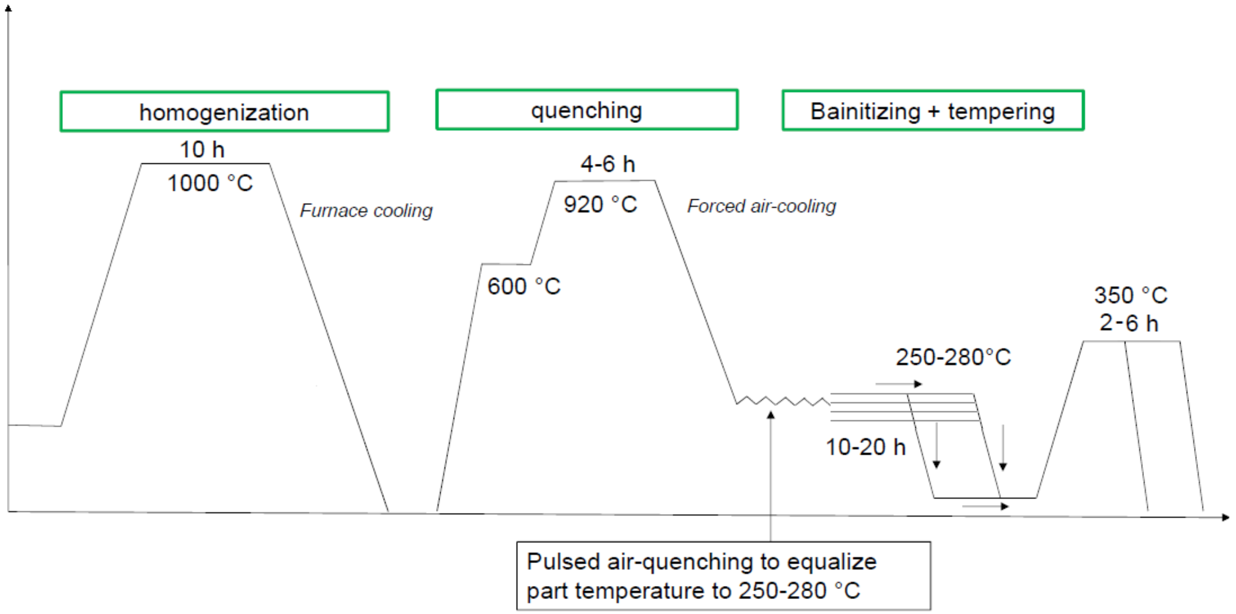
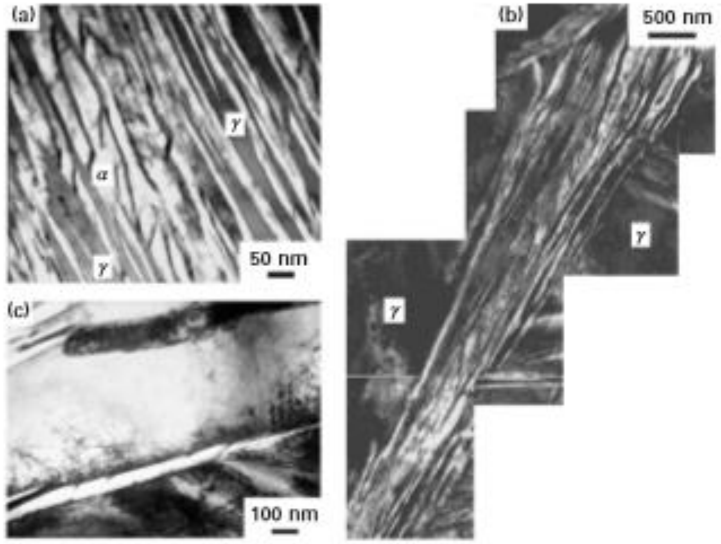
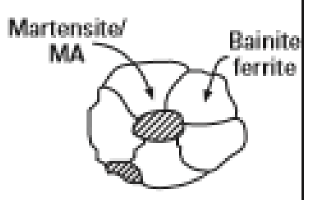
Overview of the project

- The objective of the project is to **develop a process to obtain a carbide-free bainitic microstructure**
- The new heat treatment process is expected to provide a hardness between **400 and 450 HB** (350-400 HB currently hardness of Q&T martensitic steel)
- Guarantee the reliability, the impact toughness should be retained at the same level (V-notch test mín 12 J), resulting in increased life of the mill liners.





12.7 Transmission electron micrographs of microstructure obtained at 200°C after 144 h in Fe-1C-1.5Si-1.9Mn-1.3Cr (wt%) steel. α is bainitic ferrite and γ is retained austenite.

<table>
<tr><th>Bainite</th><th>Morphology</th><th>Bainite description</th></tr>
<tr><td>Granular bainite</td><td>Irregular ferrite with M/A</td><td>
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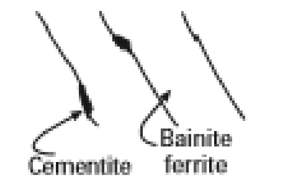
<tr><td>Lath-like upper bainite</td><td>Lath-like ferrite with cementite on lath boundaries</td><td>
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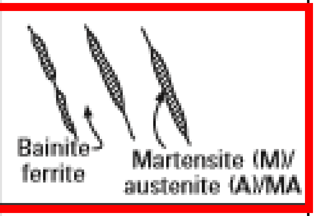
<tr><td>Cementite-free lath-like bainite</td><td>Lath-like ferrite with M/A on lath boundaries</td><td>
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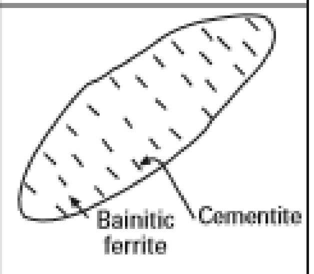
<tr><td>Lath-like lower bainite</td><td>Lath-like ferrite with cementite inside the ferrite laths</td><td>
</td></tr>
<tr><td>Plate-like lower bainite</td><td>Plate-like ferrite with cementite inside the ferrite plates</td><td>
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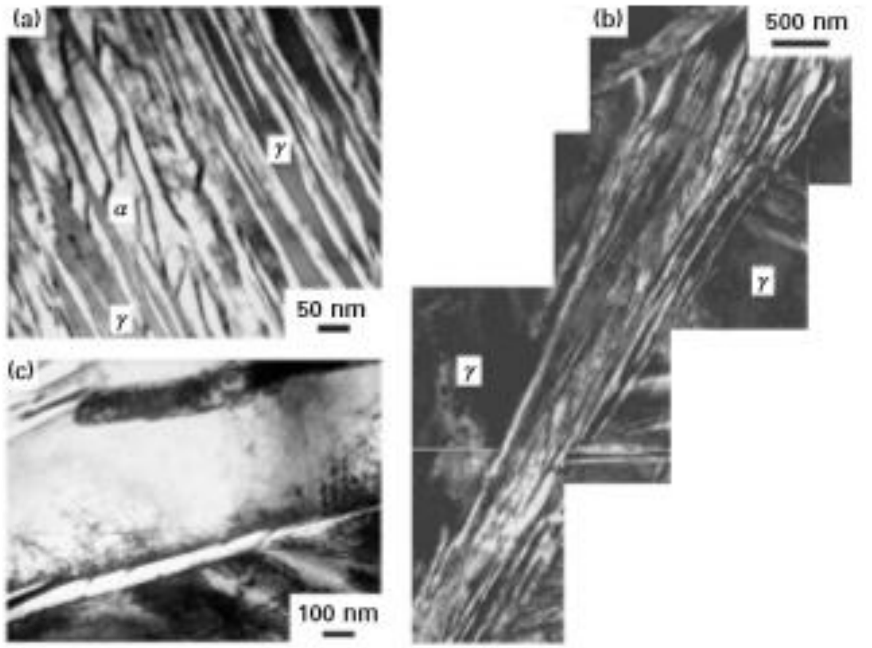
12.1 Morphological classification used in this chapter based on Zajac *et al.*'s categorisation scheme (Zajac *et al.*, 2005) and microstructural observations, including optical microscopy and scanning electron microscopy.

Carbide-free bainite:

- Carbon rejected to residual austenite → stabilized austenite at room temperature;
- Microstrucure: bainitic ferrite laths interwoven with thin films of untransformed austenite;

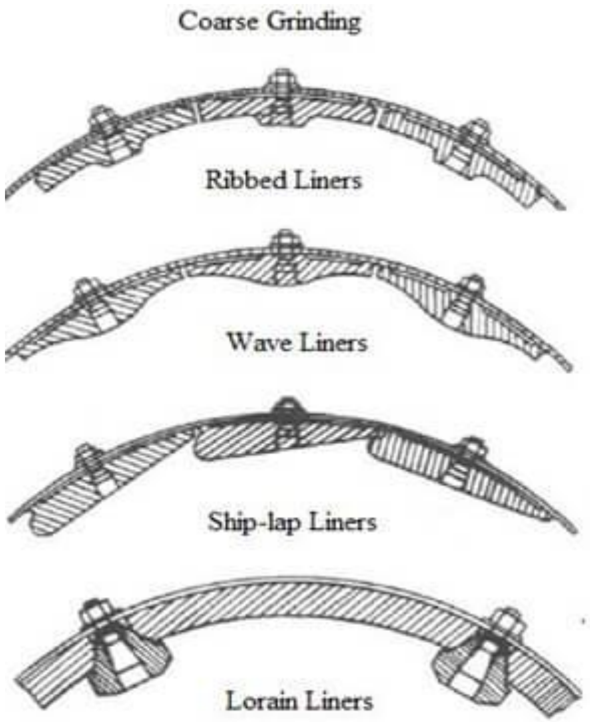
12.2 Transmission electron micrograph of carbide-free bainitic microstructure formed by air cooling after forging in Fe-0.30C-1.50Si-3.50Ni-1.44Cr-0.25Mo wt% steel. α is bainitic ferrite and γ is austenite.

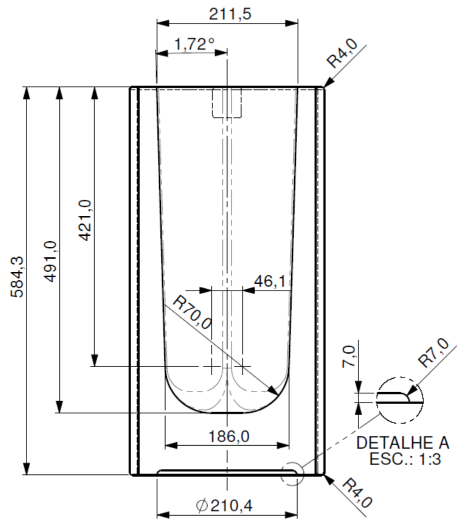
Nanobain steel: refined microstructure of a carbide-free bainite



12.7 Transmission electron micrographs of microstructure obtained at 200°C after 144 h in Fe-1C-1.5Si-1.9Mn-1.3Cr (wt%) steel. *α* is bainitic ferrite and *γ* is retained austenite.

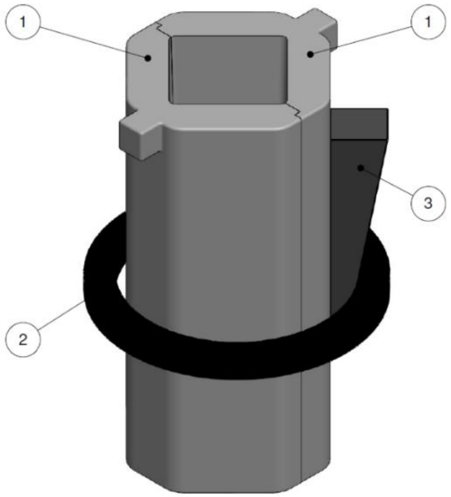
- Important aspect:
  - phase morphology → laths / plates
- Austenite;
- Bainite;
- Influence of composition and heat treatments.





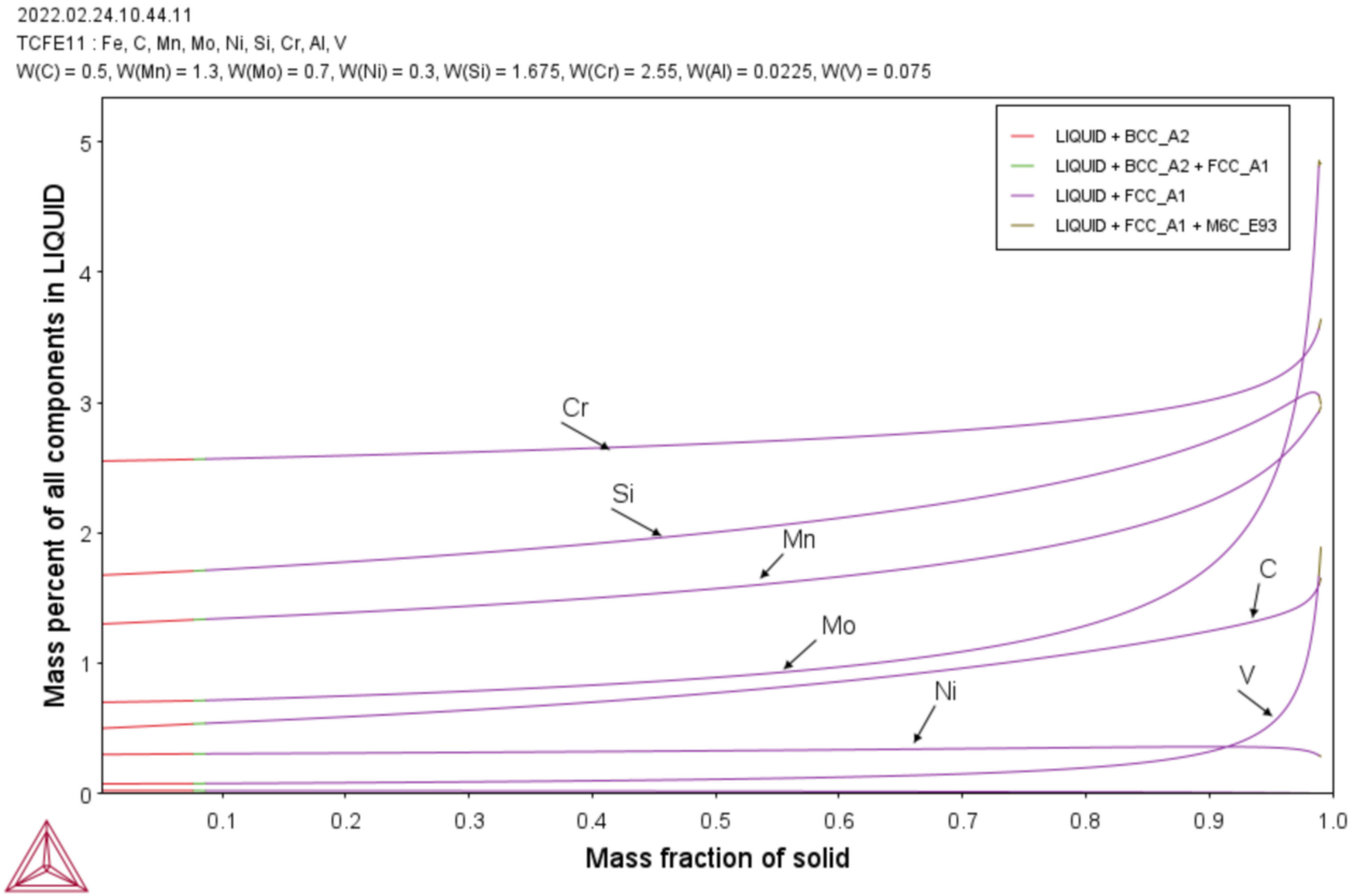
Methodology

- Production of 2 ingots
    - Homogenization tests and dilatometric tests.
    - Pilot scale heat treatment
    - Mechanical tests (impact and hardness measurement)



%C	%Si	%Mn	%Cr	%Mo	%Ni	%V	%N
0,48 – 0,53	1,55 - 1,80	1,20 – 1,40	2,40 – 2,70	0,60 – 0,80	0,20 – 0,40	0,05 – 0,1	0,015 max

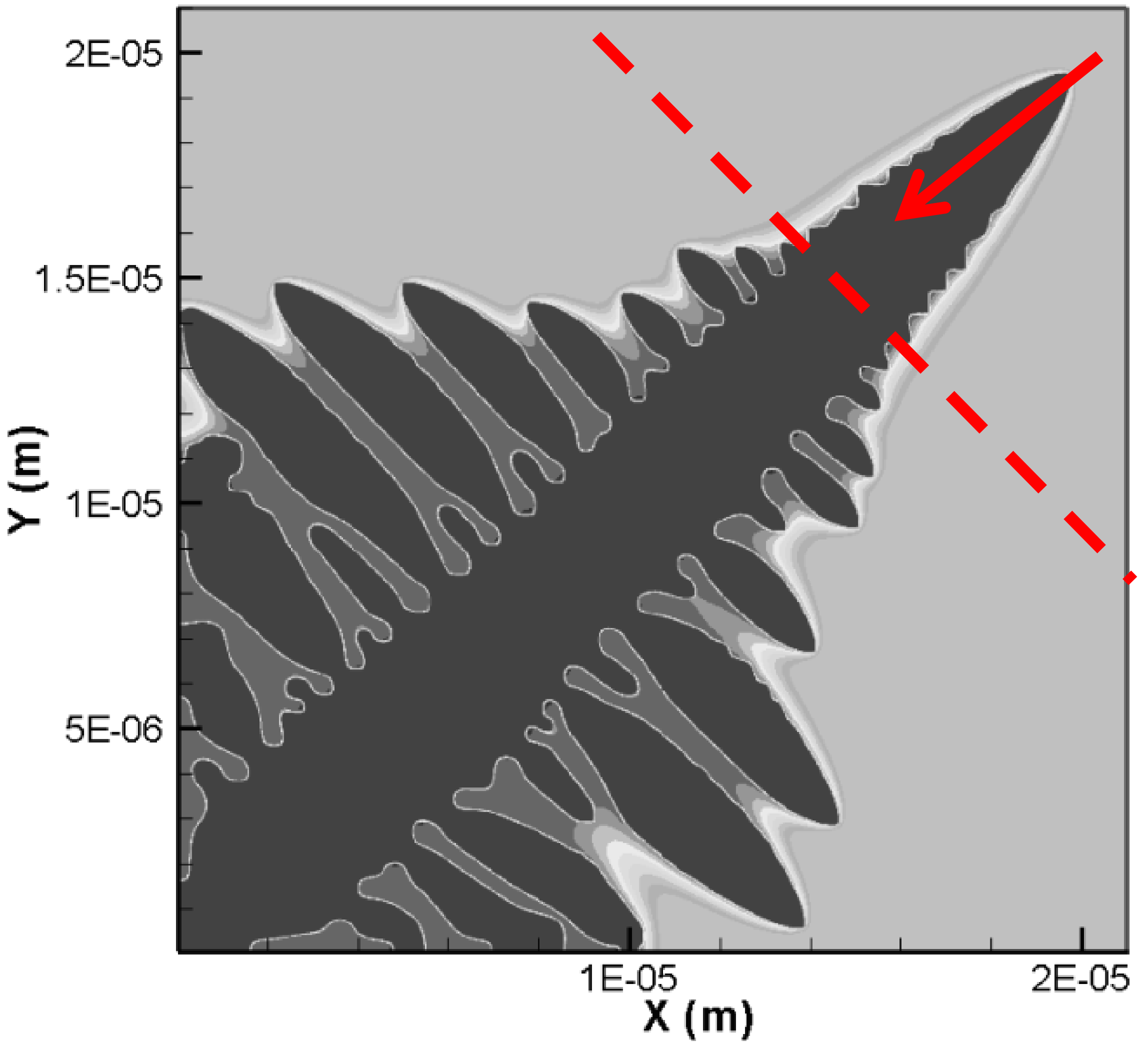
Study of Homogenization Step

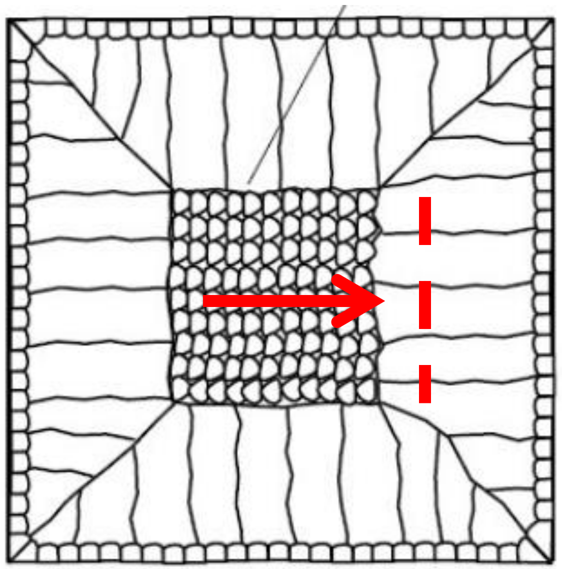


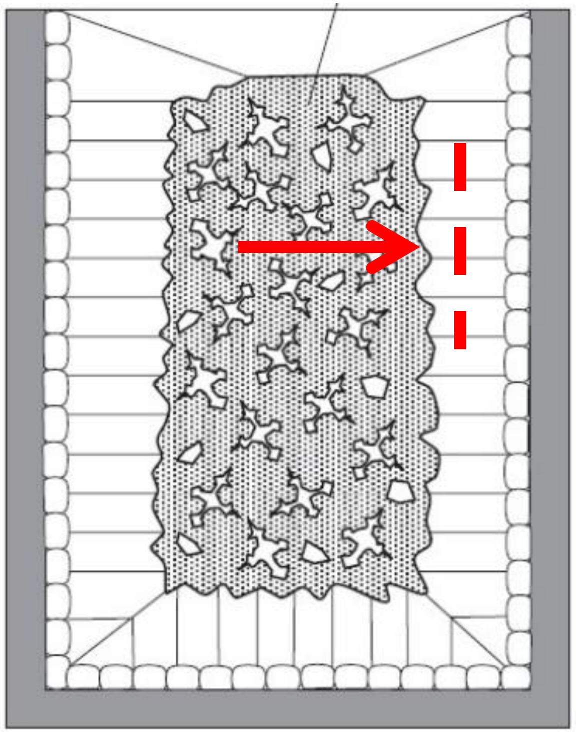
- Using Thermocalc® it was possible to determine the Evolution of the chemical composition of the liquid in funcion of fraction of solid.
- Chemical composition gradient
- Relation between the chemical composition of the first solid to form (dendrite center) with the last solidified part (interdendritic region)

Study of Homogenization Step

Metallographic analysis

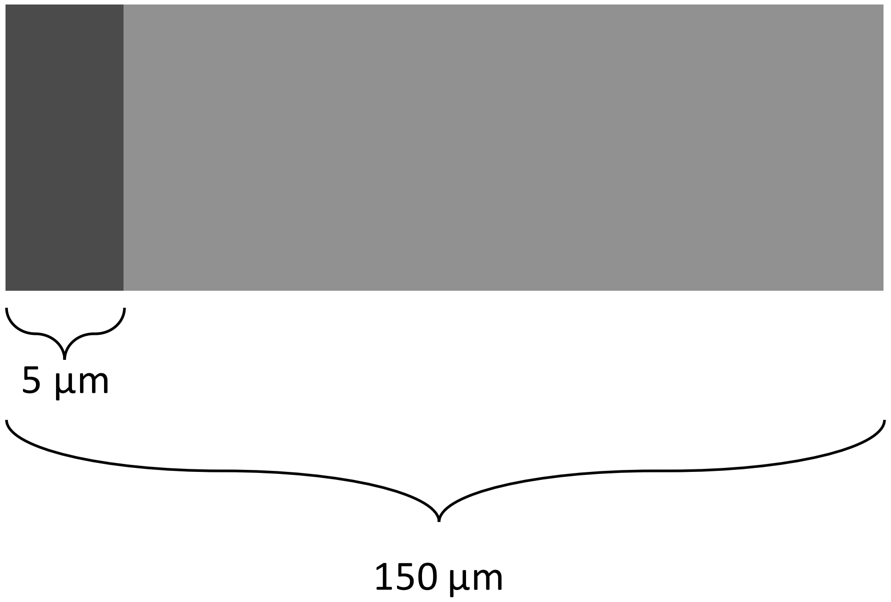


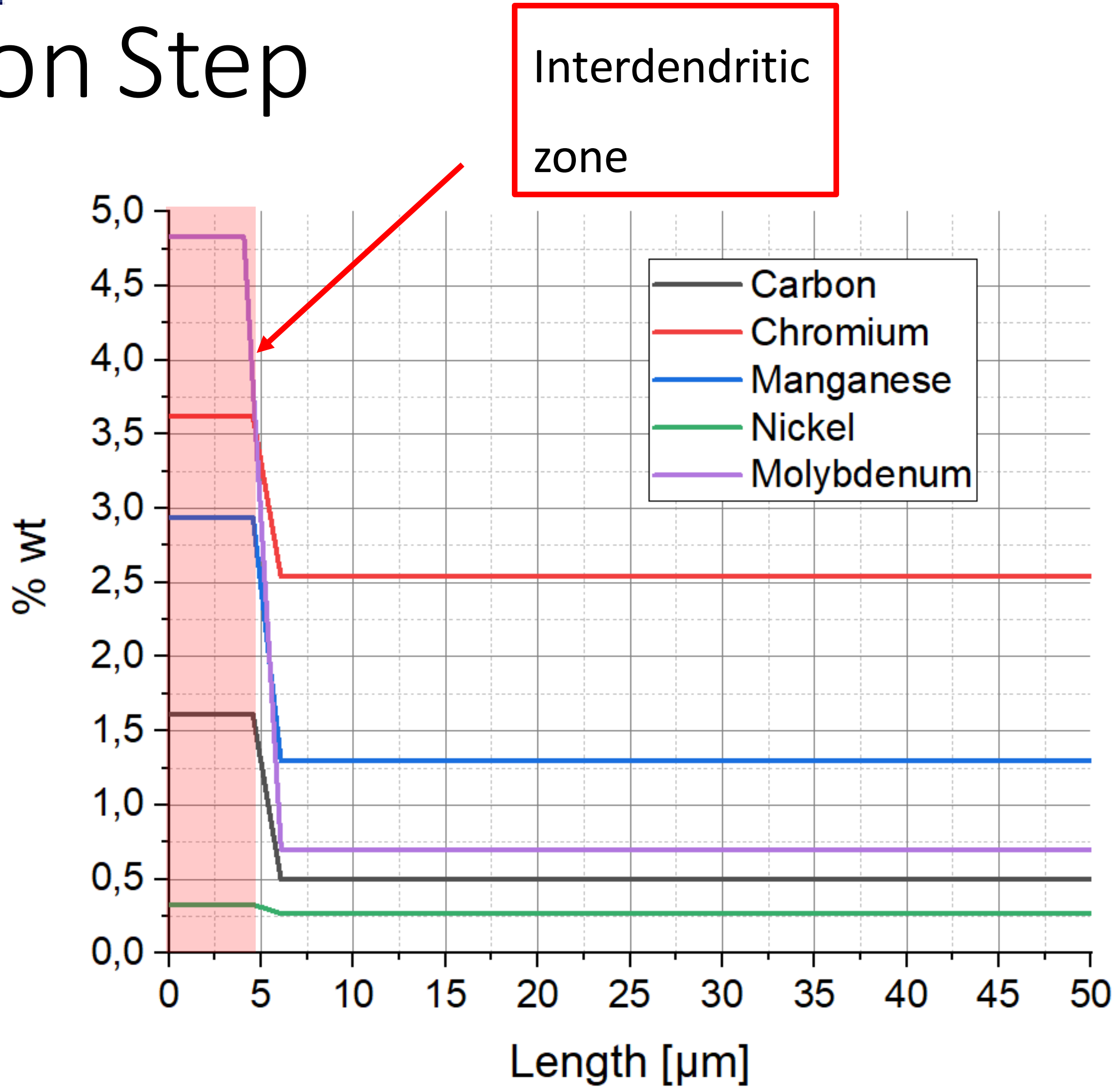




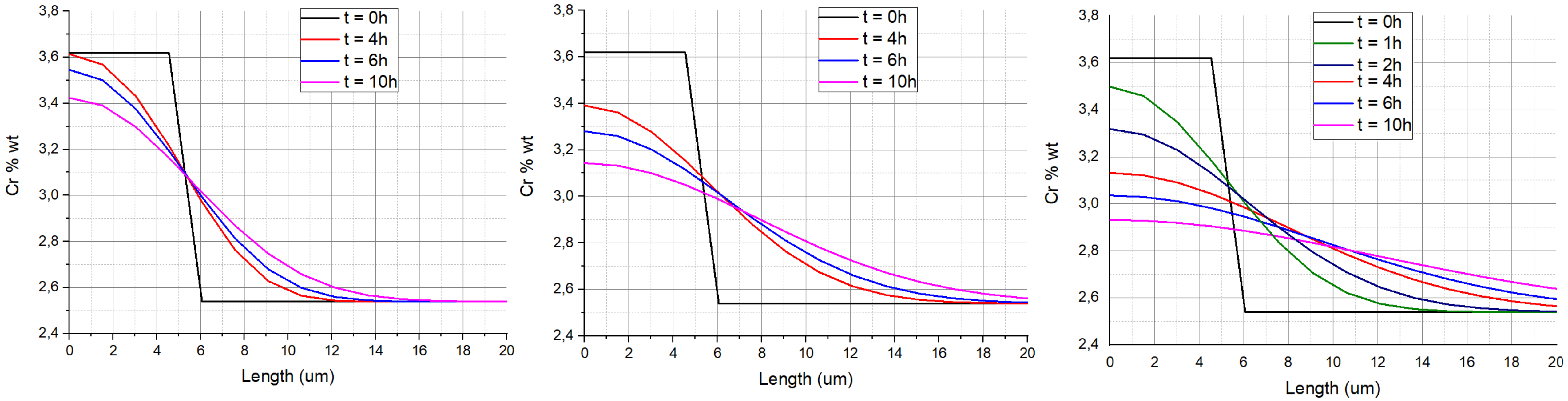
Study of Homogenization Step

- Using ThermoCalc®, the chemical composition of interdendritic and dendritic zone was estimated and the phenomenon was modeled according to the scheme below:





Chemical composition gradiente effect of temperature



1000°C

1050°C

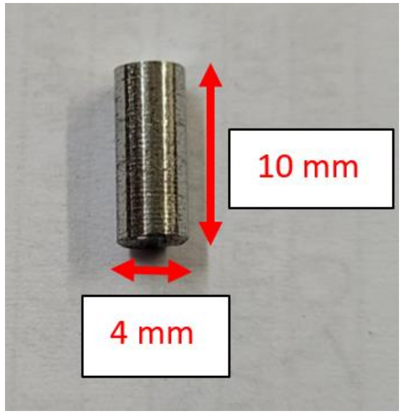
1100°C

- 1000°C for 10h
- 1050°C for 4h
- 1100°C for 2h

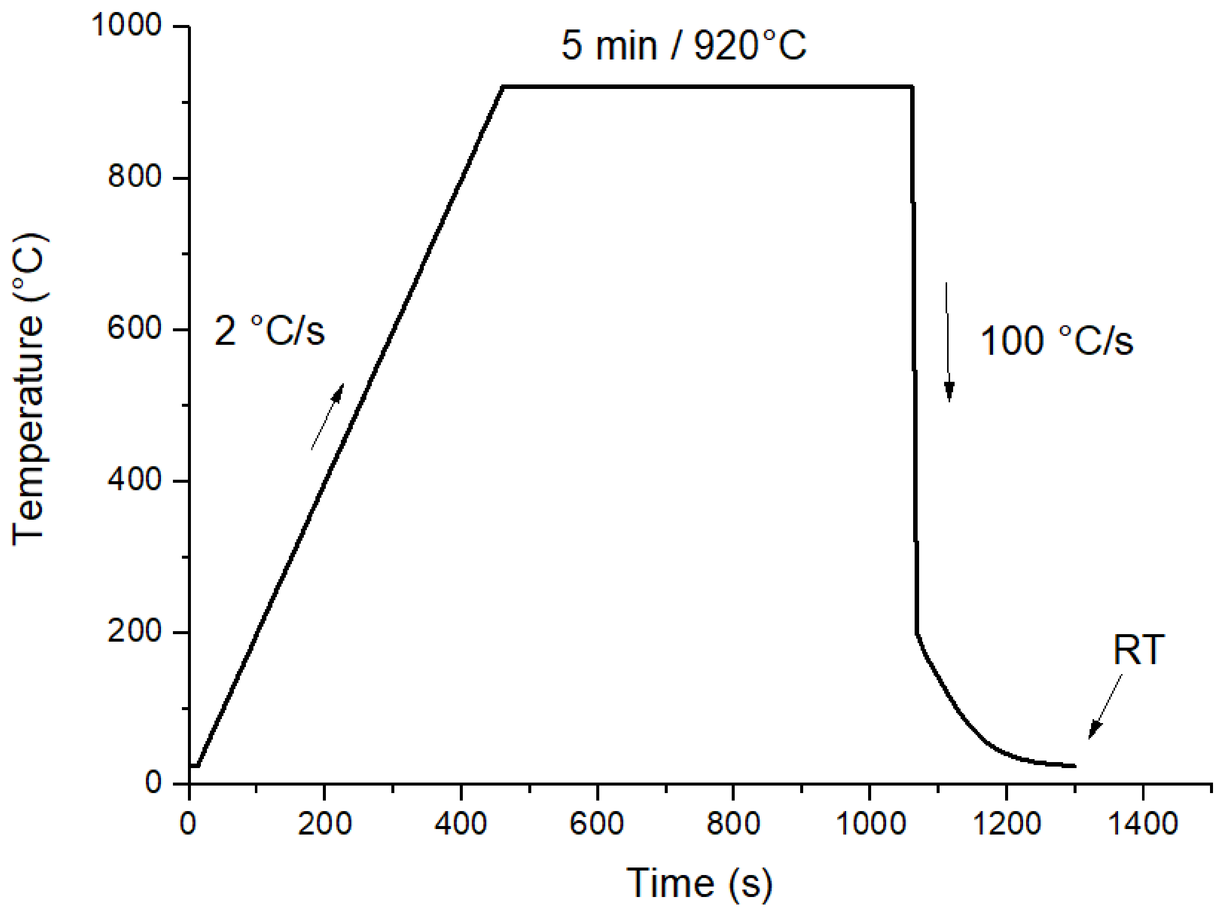
All these parameters produces the same chemical composition gradient

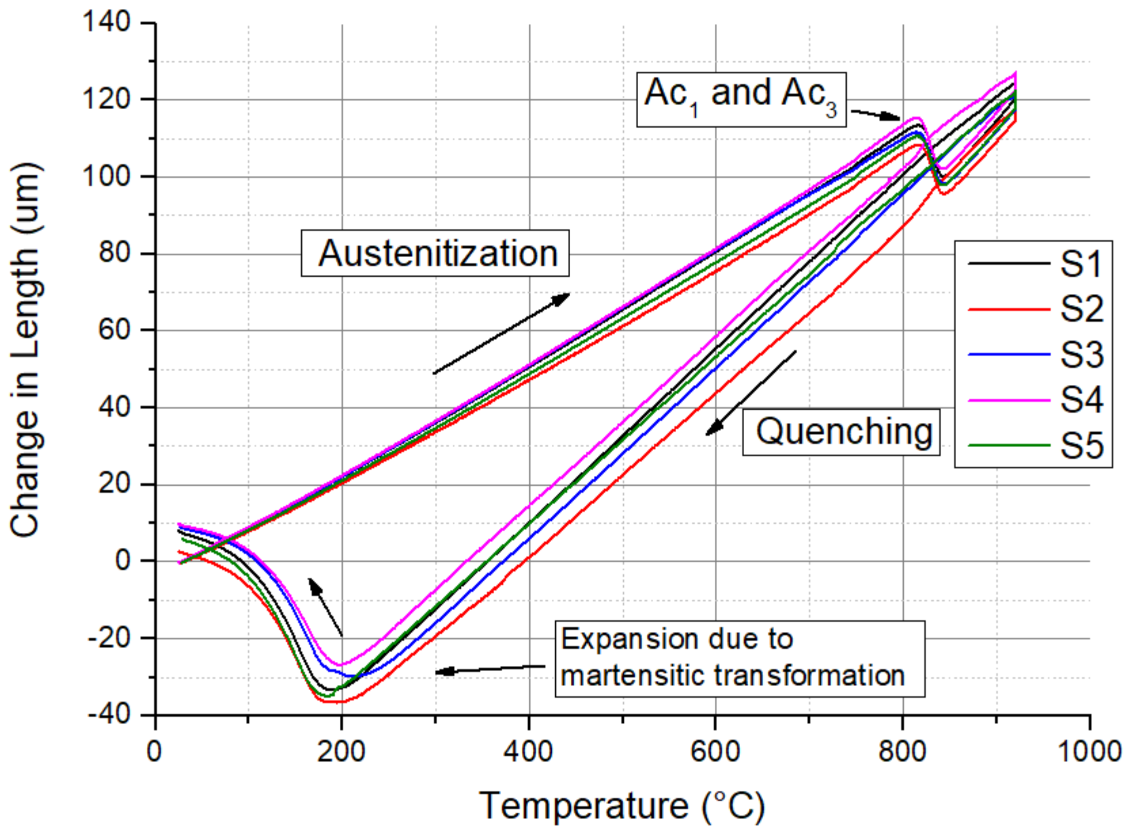
Dilatometry tests

- As soon as the specimens from the homogenized (at 1000°C for 10h) ingot were machined, the first dilatometer tests began
- The first experiments carried out were the quenching experiments to determine the temperature Ms of the alloy (martensite start temperature)
- The thermal cycle used to determine the Ms temperature was:
  - Austenitization at 920°C for 10 minutes followed by quenching to room temperature at a rate of 100°C/s

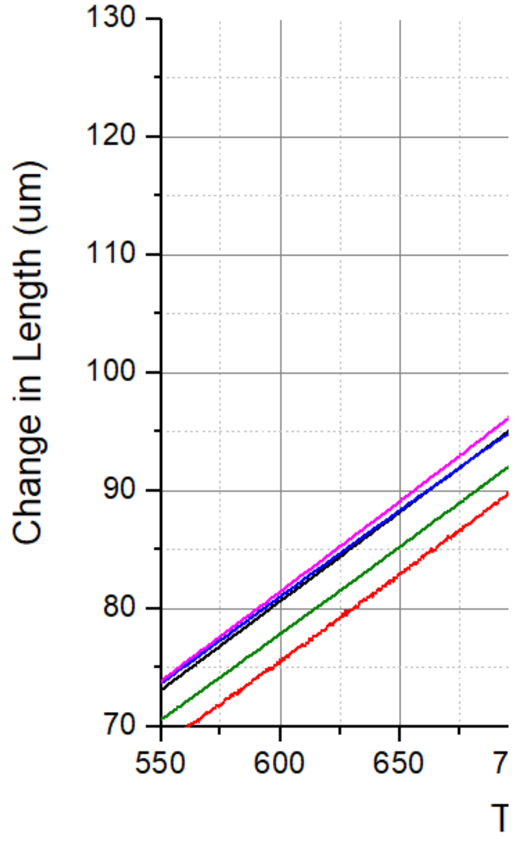


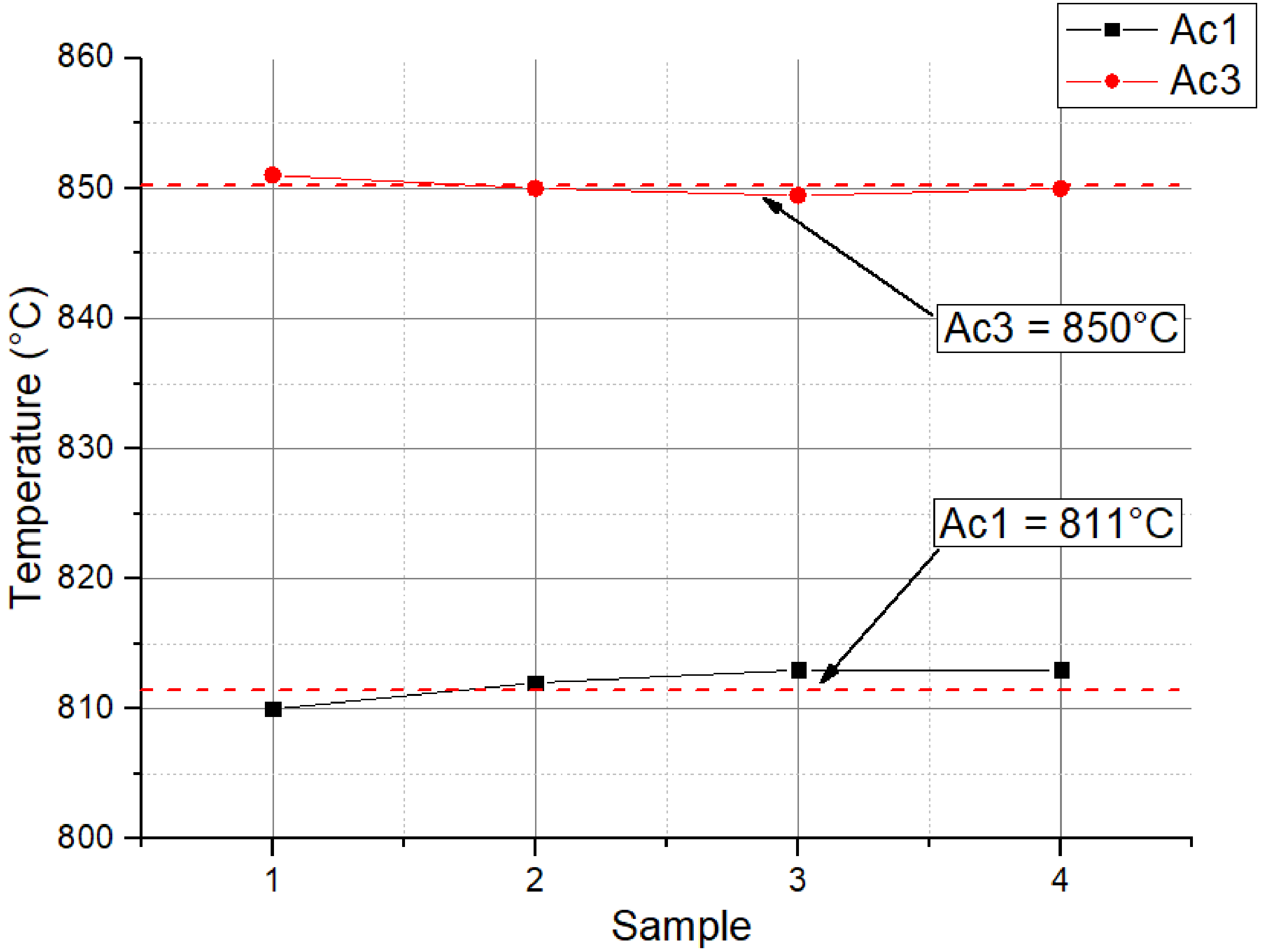
Dilatometry tests – determination of A_{c1}, A_{c3} and M_s

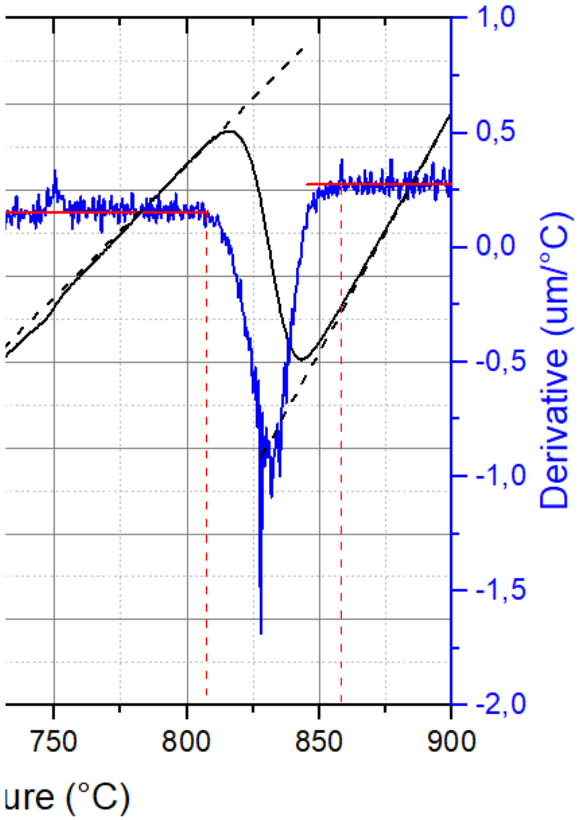




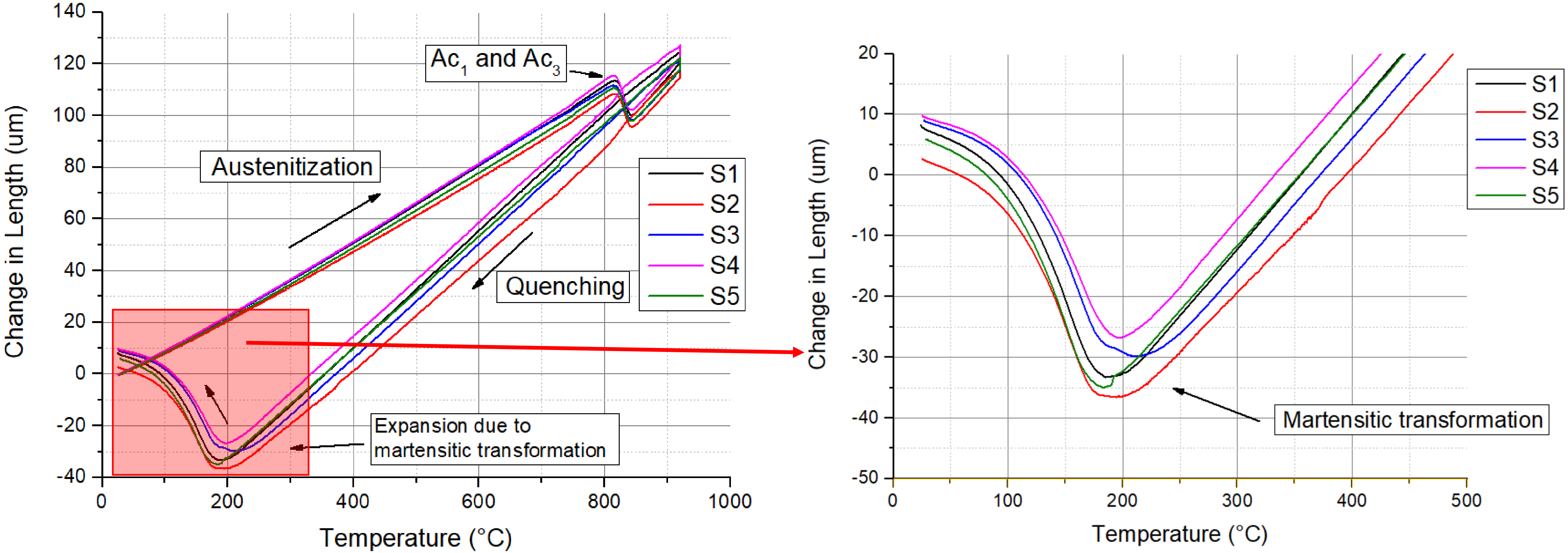
Determination of A_{c1} and A_{c3}



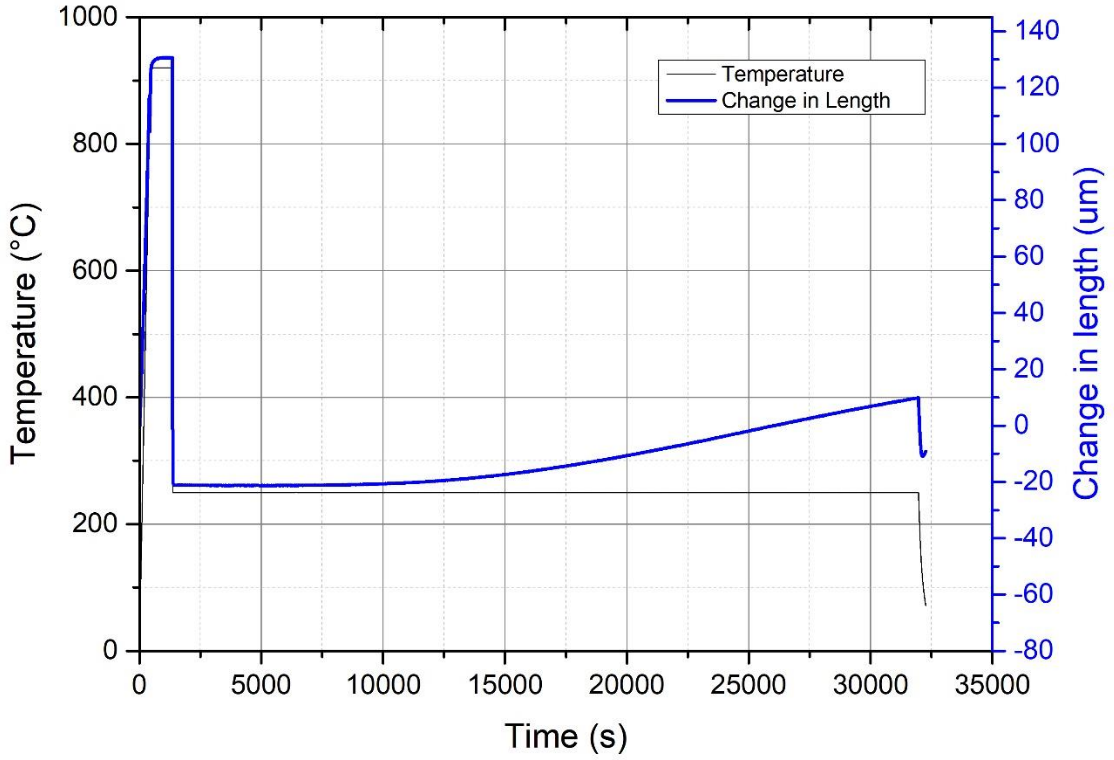




Quenching – M_s determination

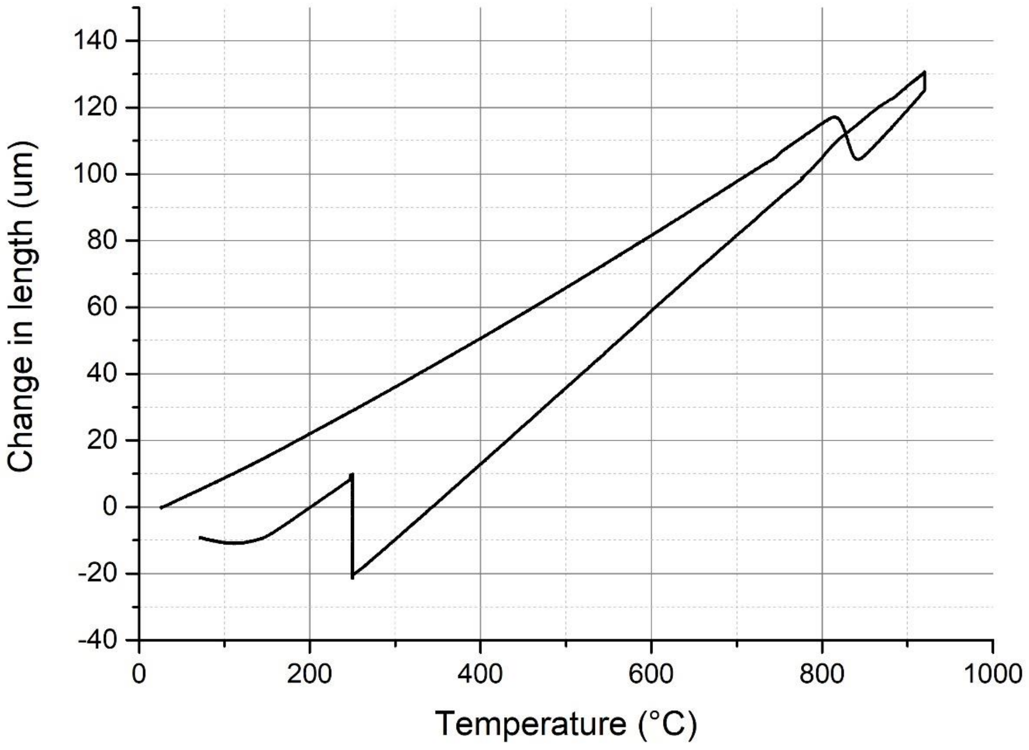


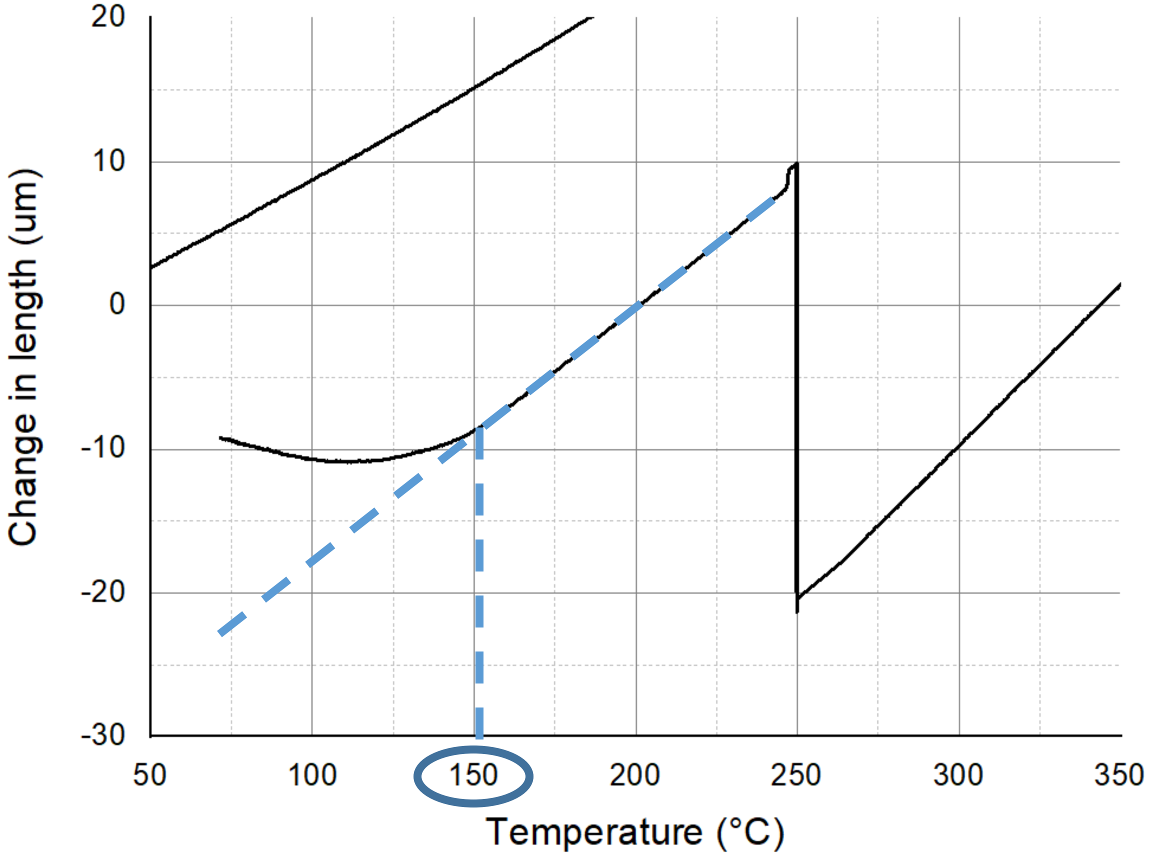
Bainitizing step – Ms+20°C_8h



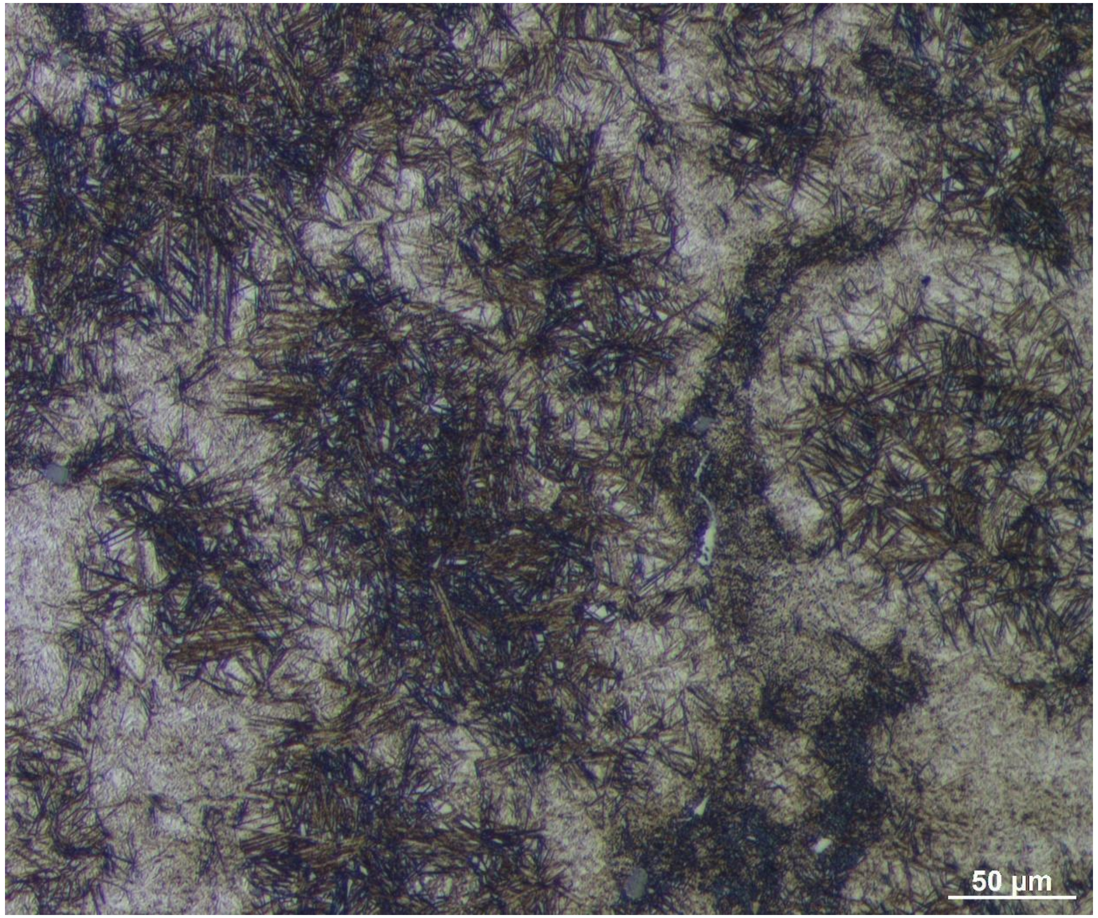
- Incomplete bainitic transformation
- Evidence of martensitic transformation after bainitizing step
- Probably during bainitizing, not enough carbon was partitioned to austenite to stabilize the remaining austenite

Bainitizing step – Ms+20°C_8h

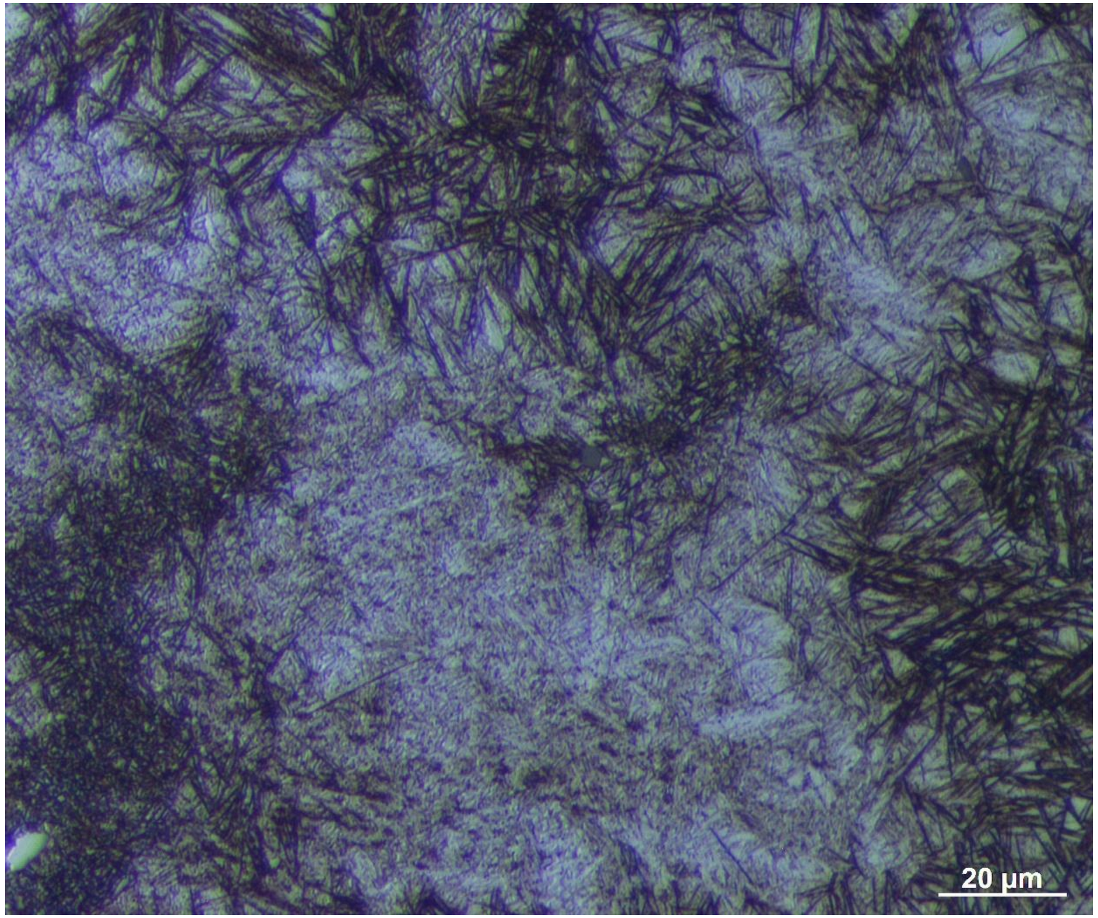




Microstructure - Ms+20°C_8h

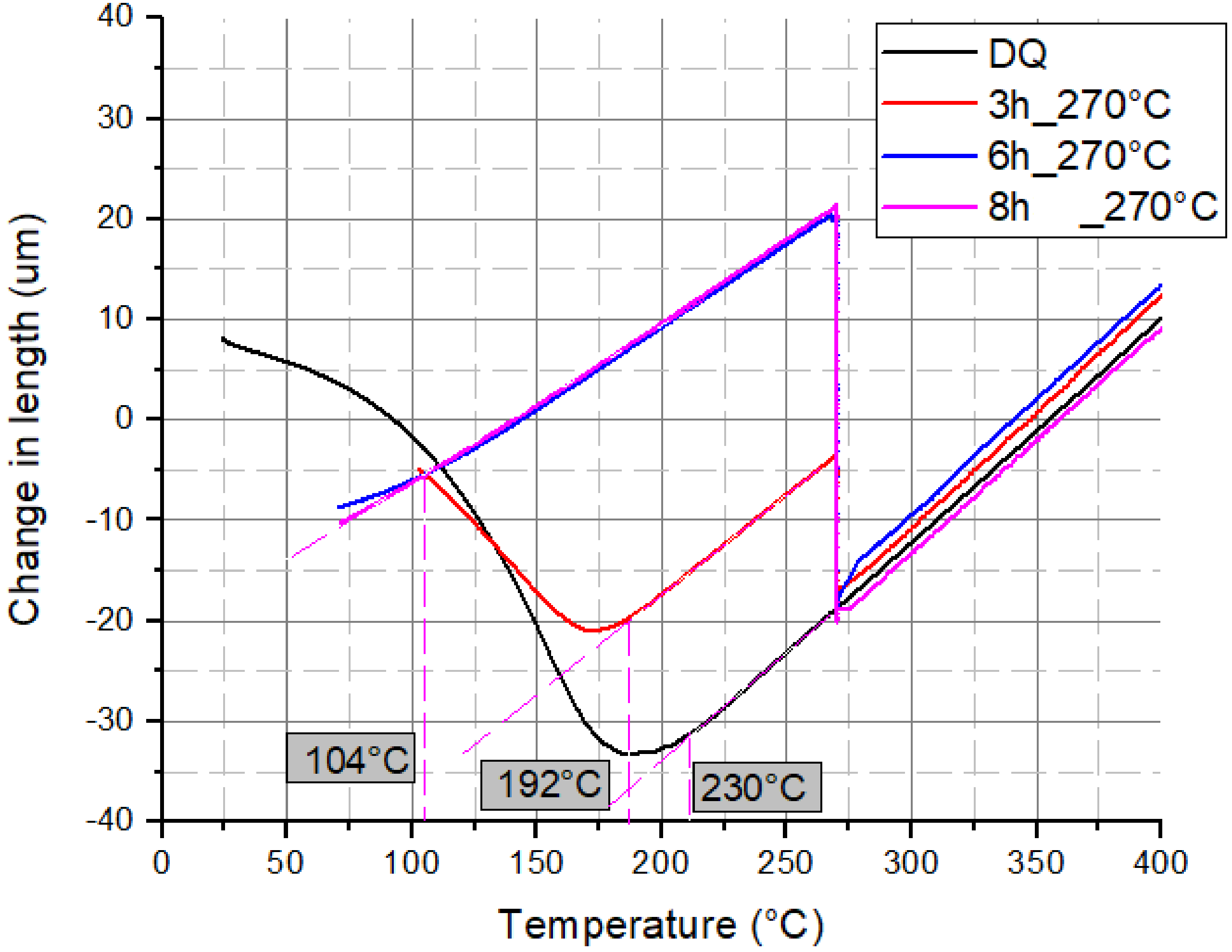


200x



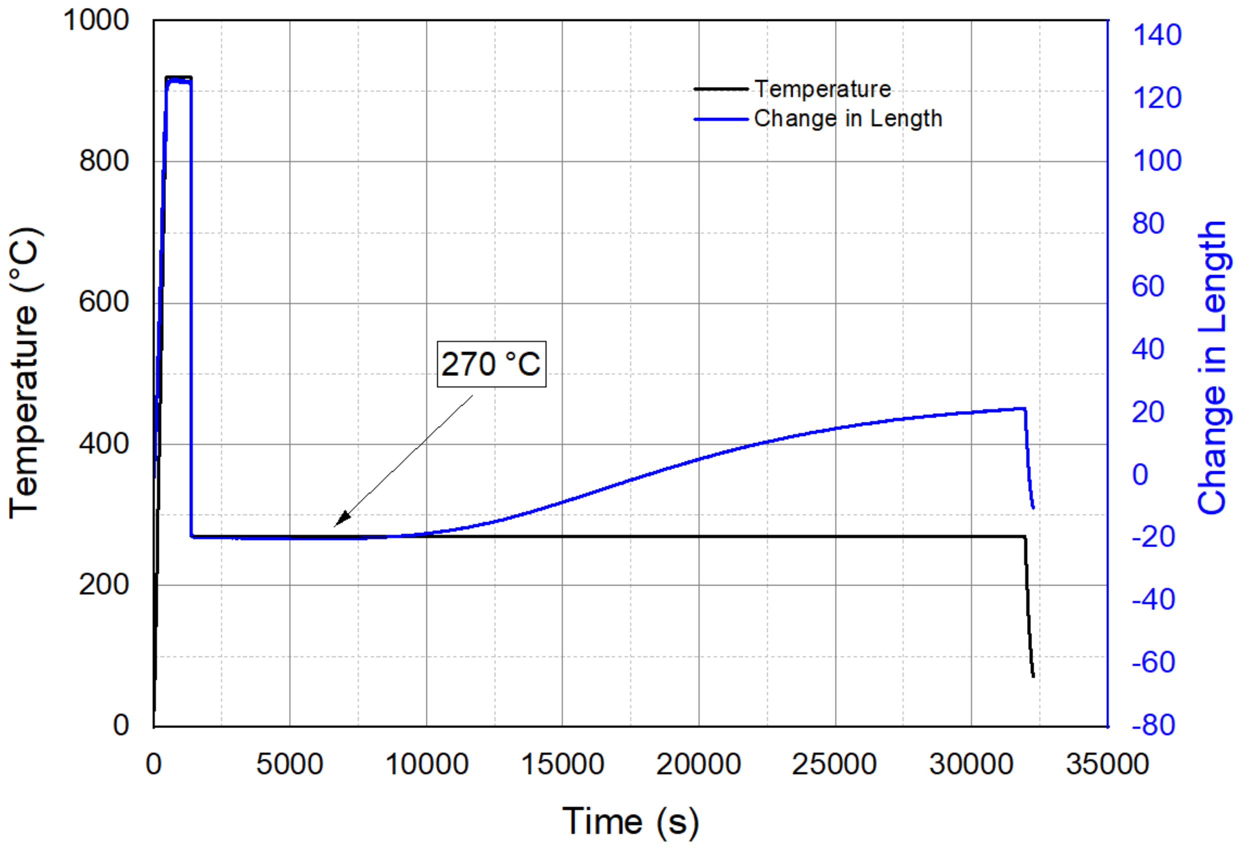
500x

Bainitizing – Ms+ 40°C



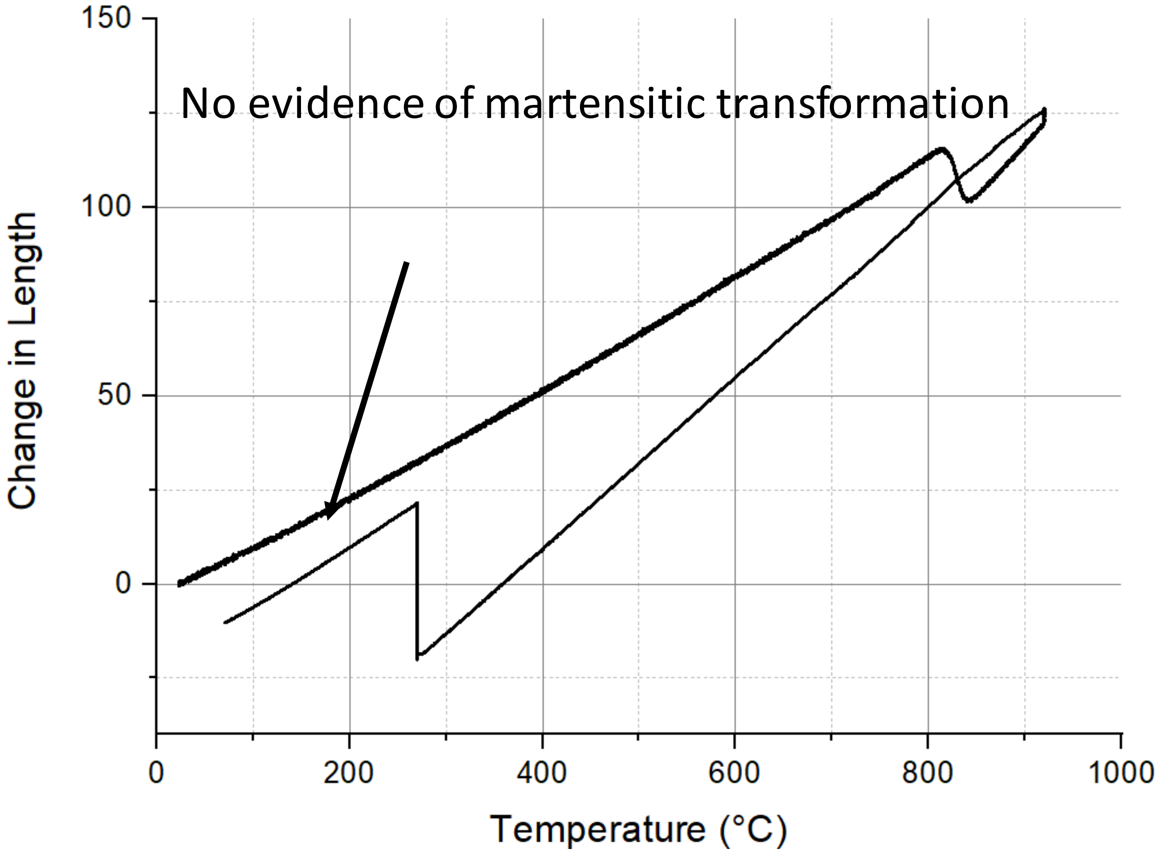
- The Ms temperature varied as a function of the incremente of the isothermal treatment time.
- The temperature variation Ms proposes a bainitic transformation mechanism, which includes partition of the alloy element from the carbide-free bainite to the remaining austenite.
- The decrease in Ms temperature is related to its enrichment of alloying elements.

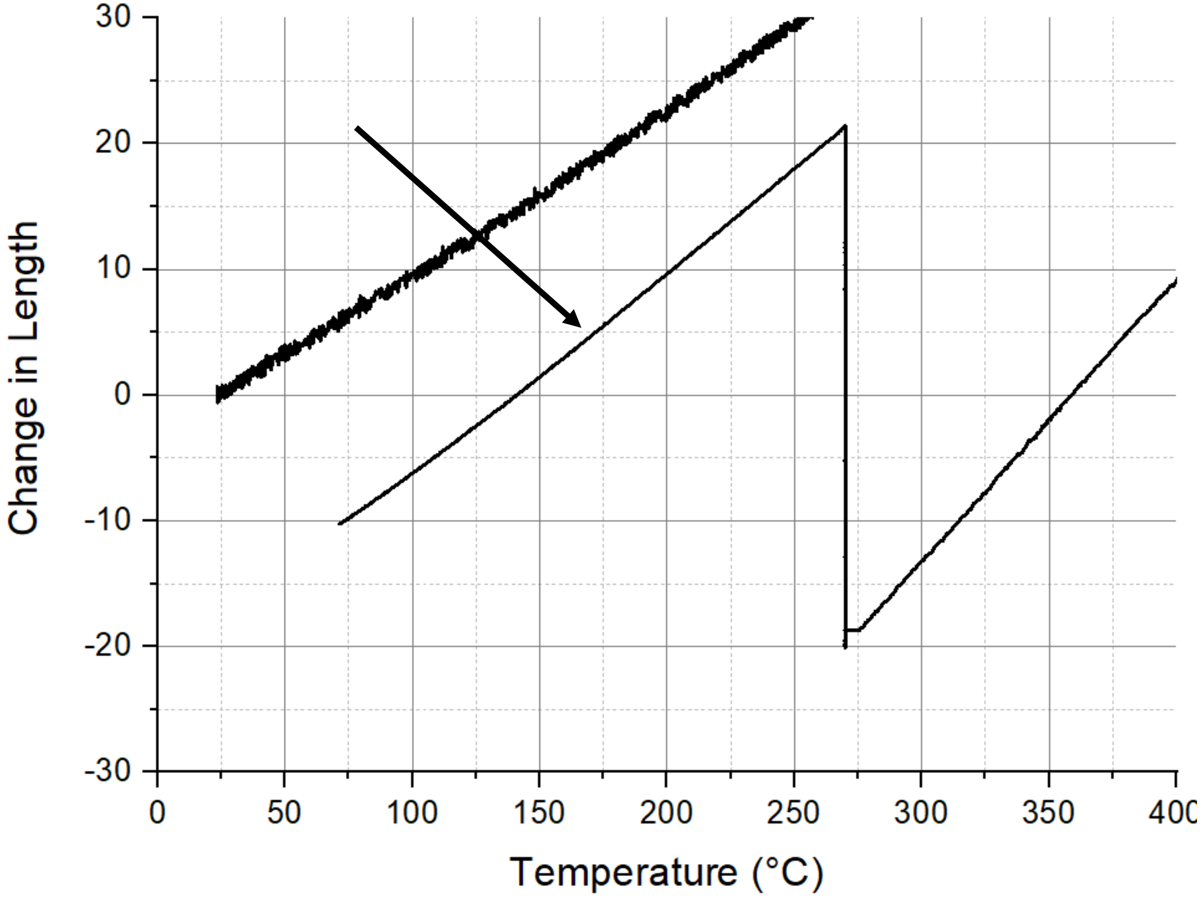
Bainitizing step – Ms+ 40°C_8h



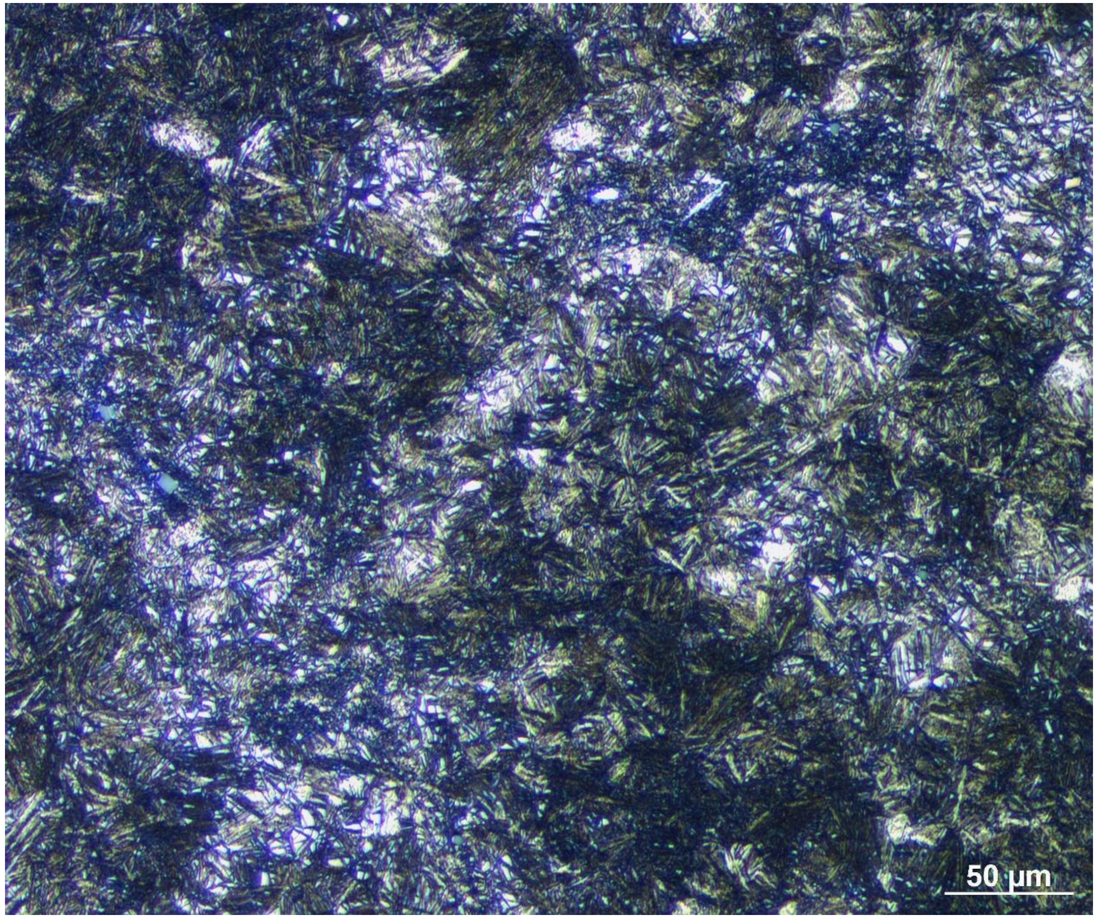
- Increasing the time of isothermal holding (bainitizing step) to 8h
- It wasn't detected the expansion due to the martensitic transformation
- Complete bainitic transformation at 270°C

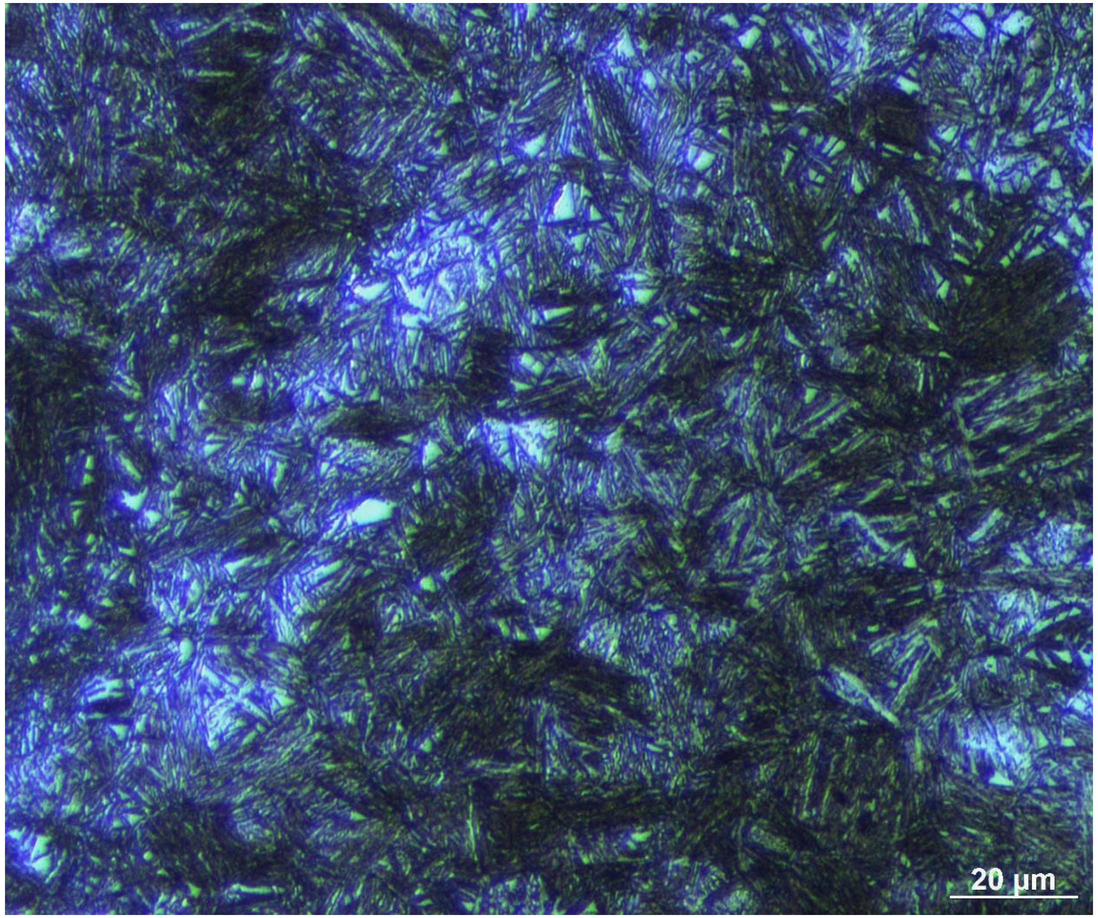
Bainitizing step – Ms+40°C_8h



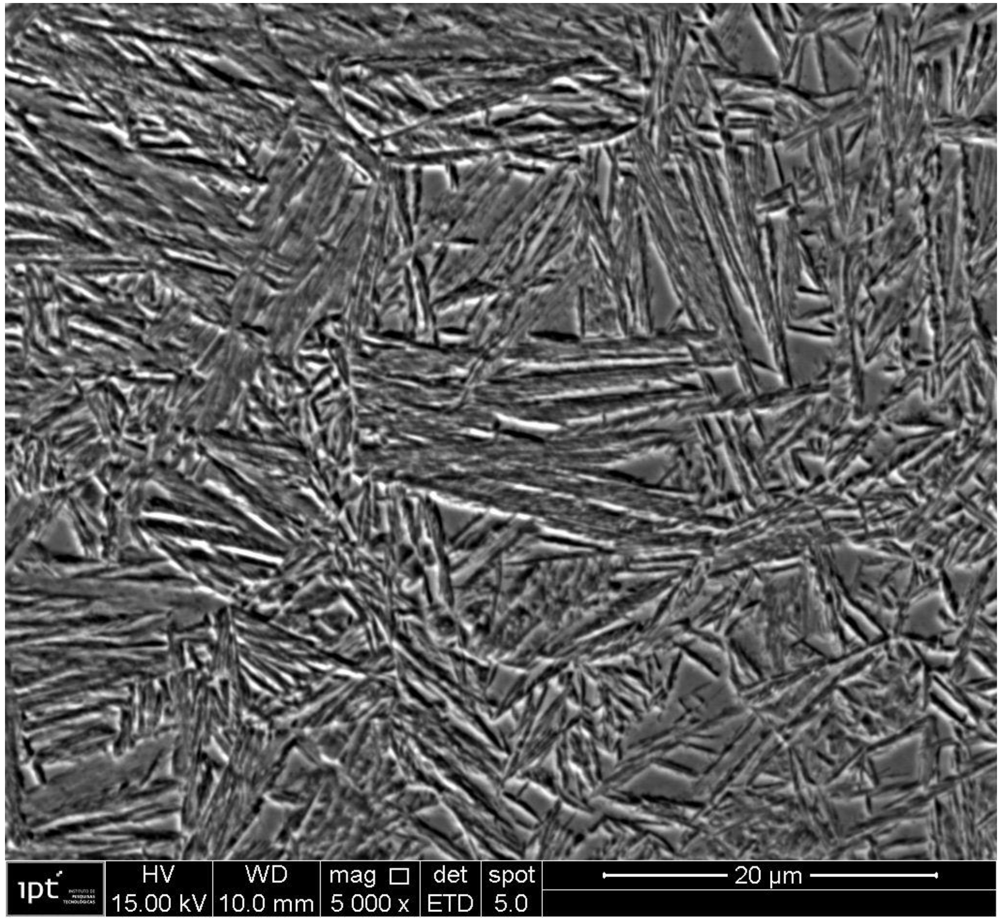


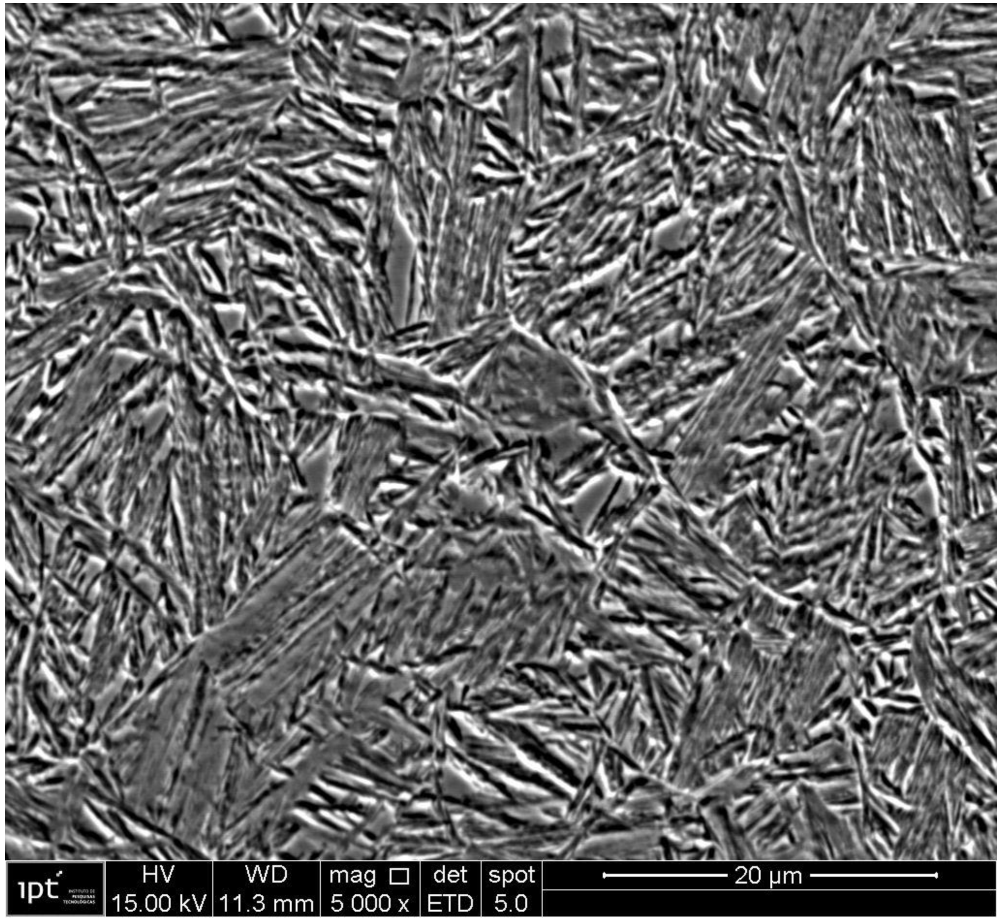
Microstructure - Ms+40°C_8h



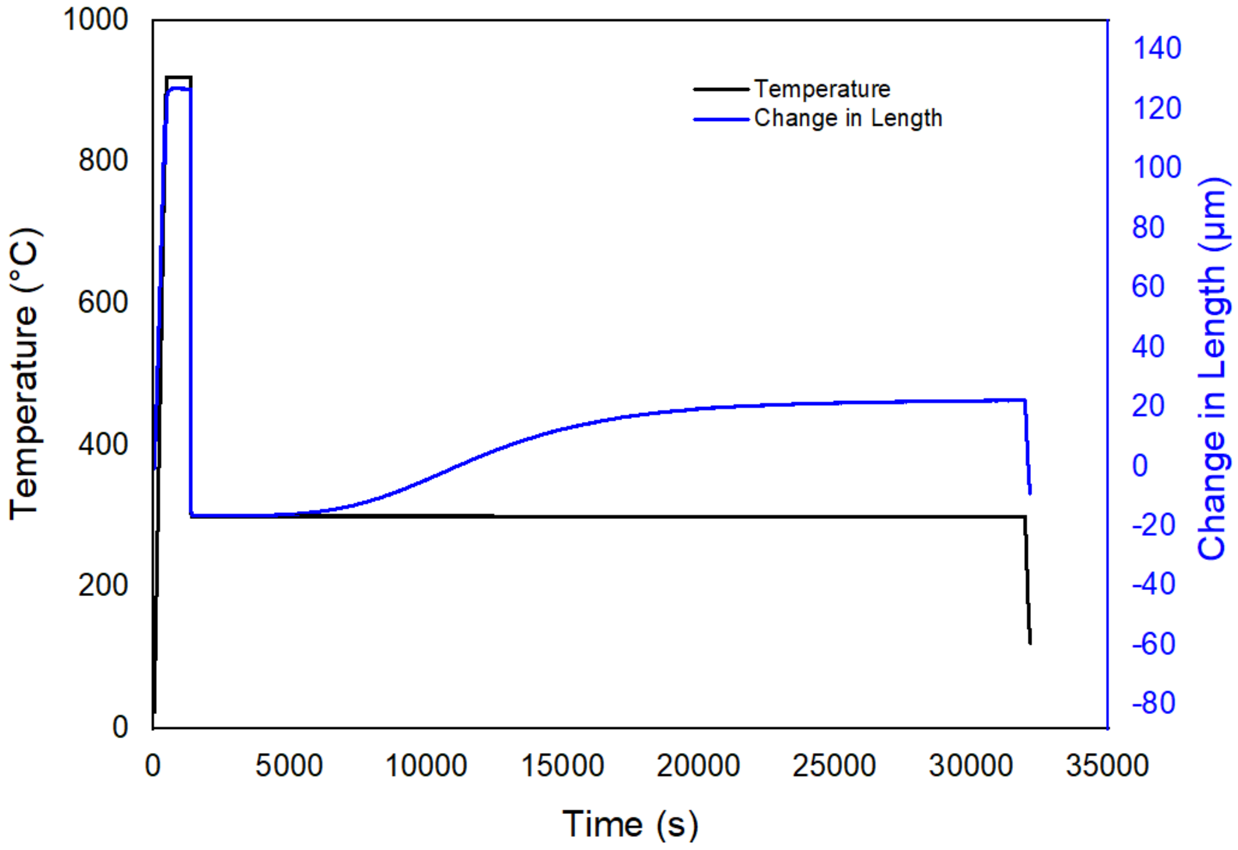


Microstructure - Ms+40°C_8h



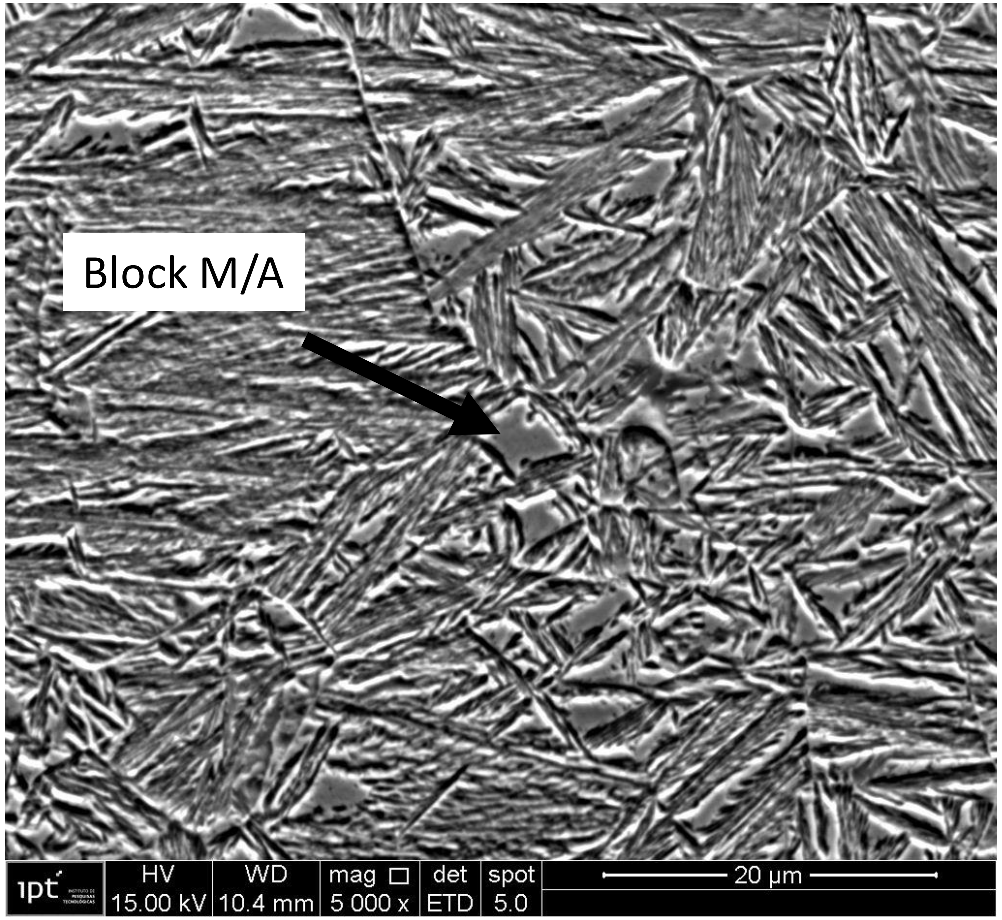


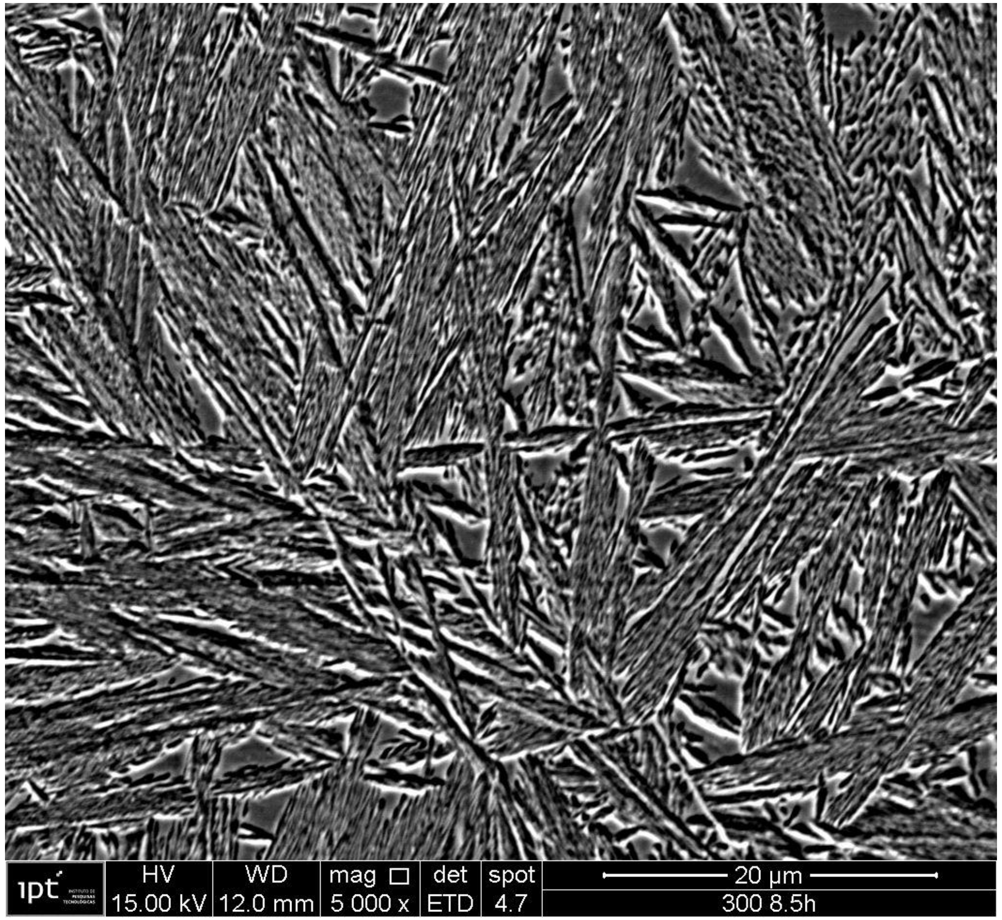
Bainitizing step – 300°C_8h



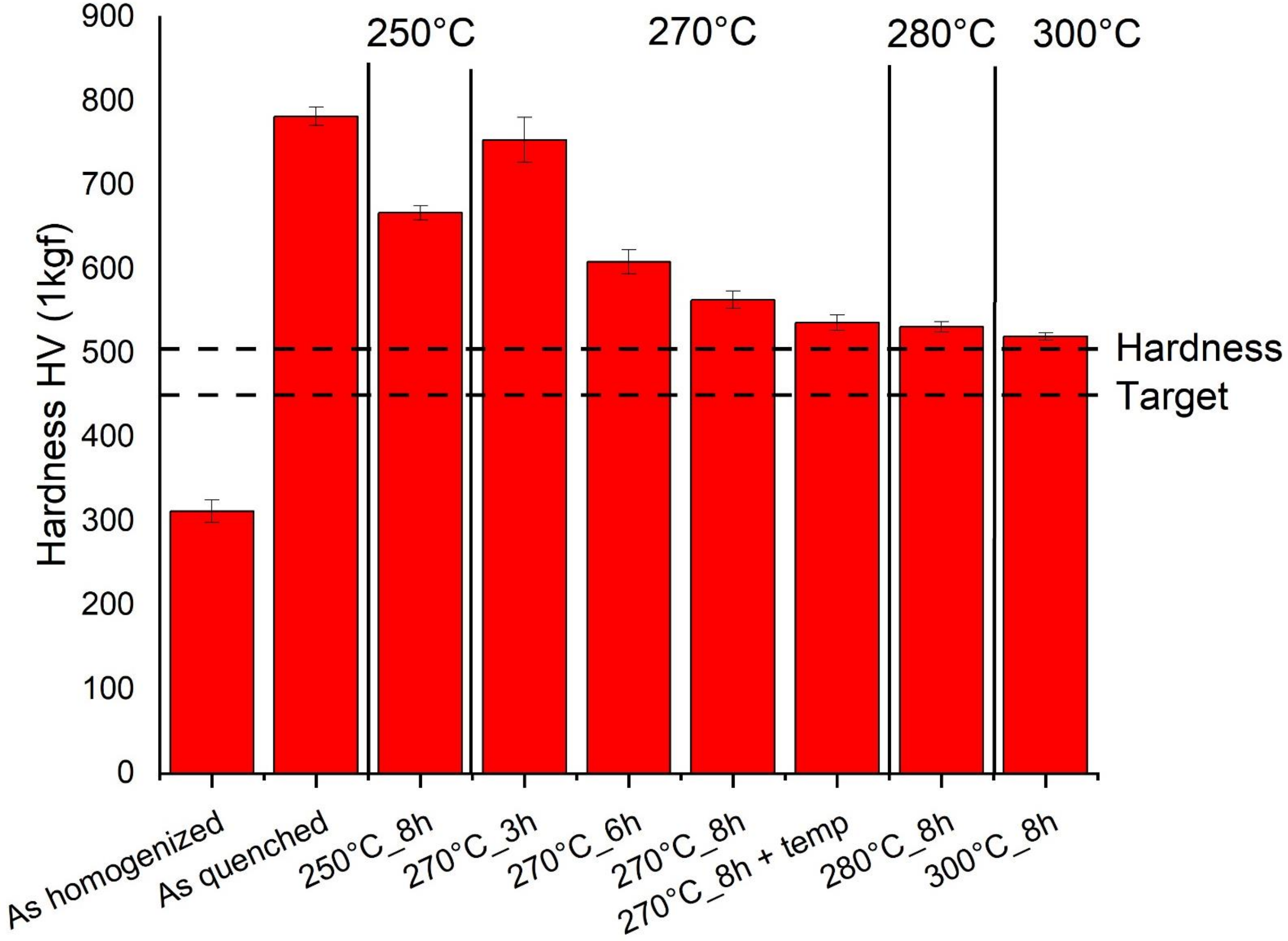
- Increasing the temperature of isothermal holding (bainitizing step) to 300°C
- No expansion was observed in cooling step after isothermal treatment
- No evidence of martensite transformation after bainitizing

Microstructure - 300°C_8h



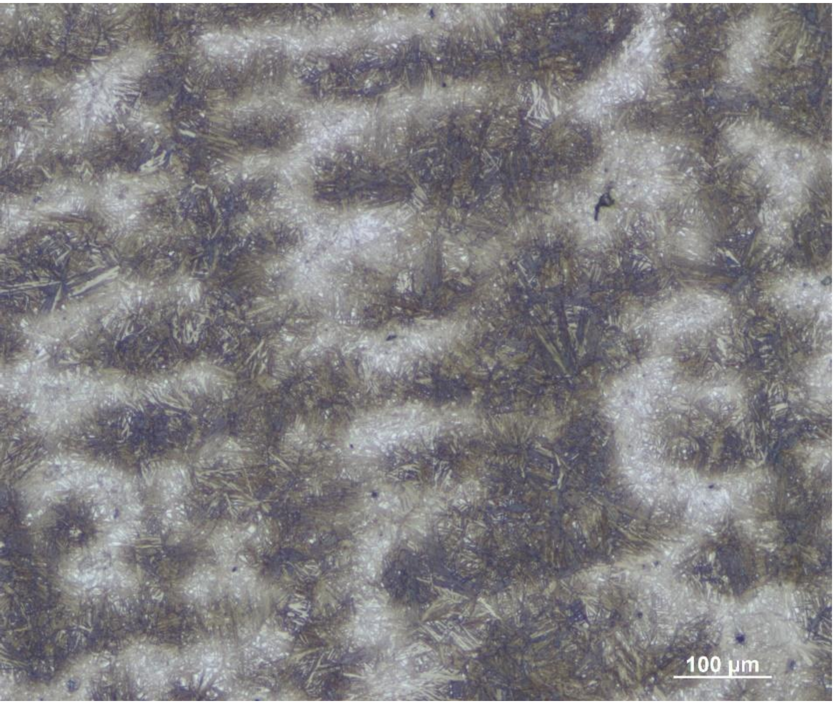


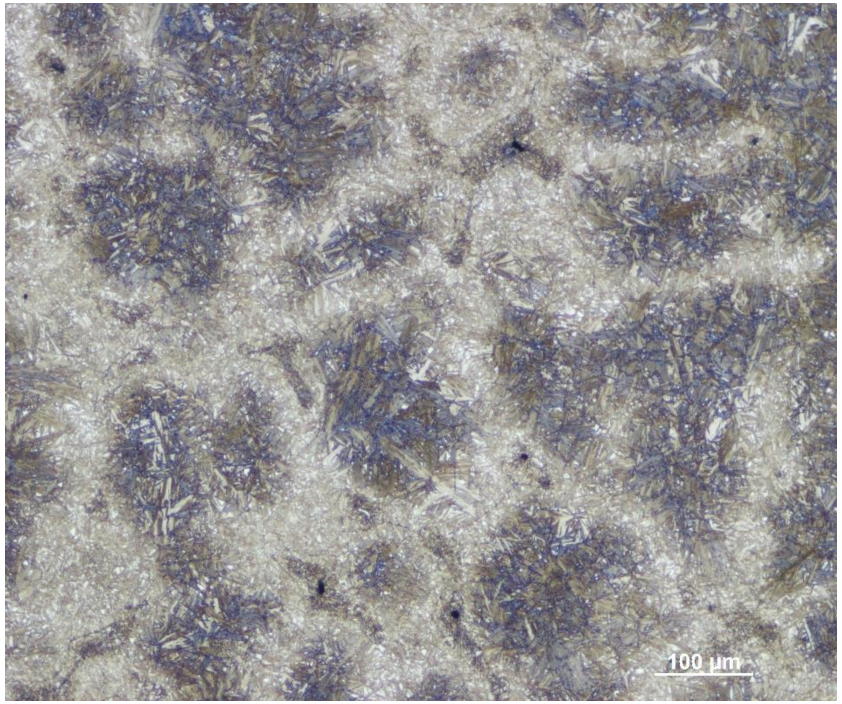
Hardness – Dilatometry scale

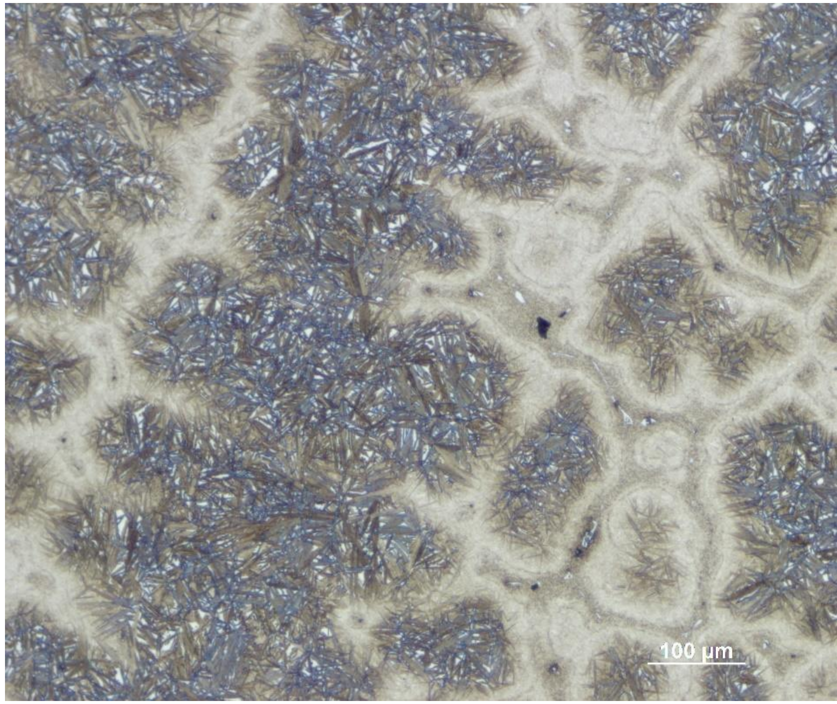


- Evolution of hardness in function of heat treatment
  - Bainitizing temperature:
  - Ms+20°C
  - Ms+40 °C
  - Ms+50 °C
  - Ms+70 °C
- Evolution of hardness at 270°C in funcion of time during bainitizing step
  - Evolution of phase volume fraction

Comparing microstructures







270°C
M_s+40°C

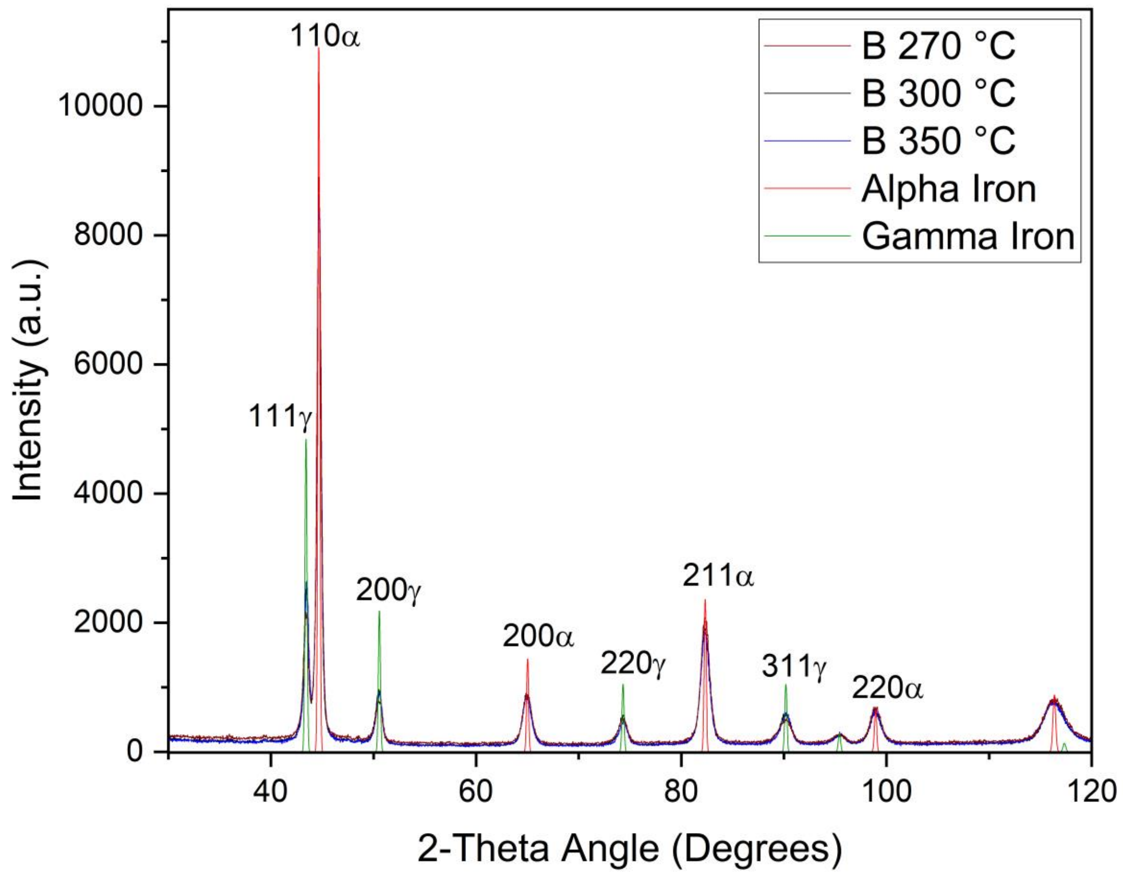
300°C
M_s+70°C

350°C
M_s+120°C

Increasing bainitizing temperature (8h)

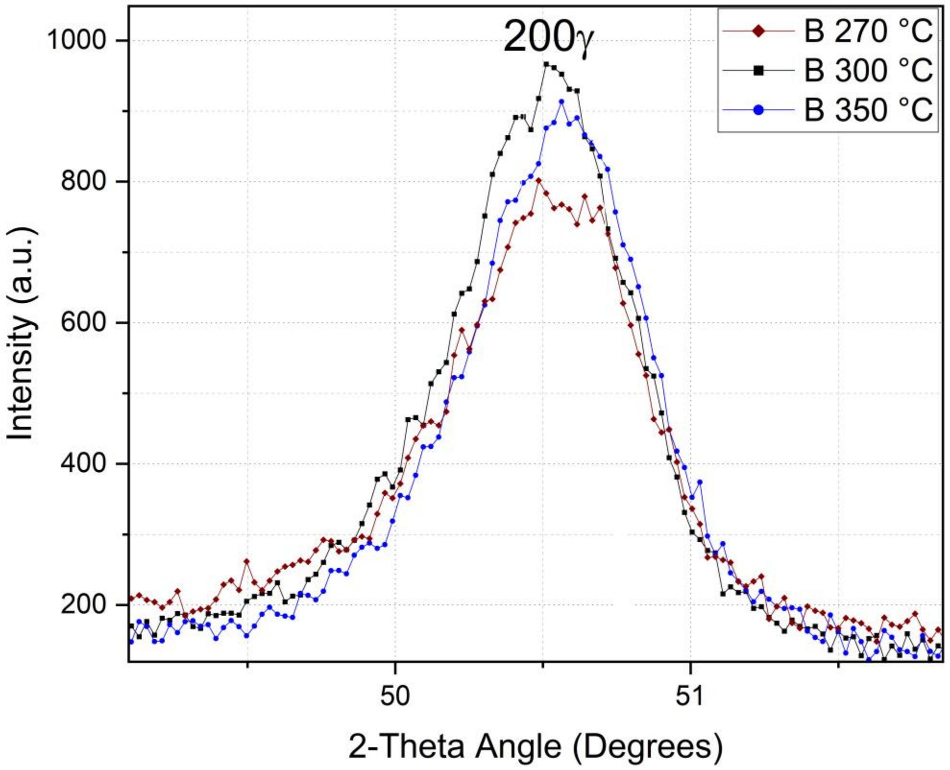
XRD results

- XRD patterns were collected from samples bainitized in different temperatures:
  - Ms+40°C
  - Ms+70°C
  - Ms+120°C



XRD results

- Correlating the austenite peaks and applying the Rietveld refinement technique it was possible to measure the austenite volume fraction of all samples



XRD results

- All bainitized samples show a similar austenite volume fraction (around 25%)
- In mill liners, the presence of retained austenite may induce the impact resistance of the mechanical device
- The stability of the retained austenite affects the repetitive impact resistance (important properties)
- In this case, only the higher austenite fraction does not improve the component's performance.

Bainitizing temperature	Phase fraction, %	
	α	γ
Ms+40 °C	76,6	23,4
Ms+70 °C	71,7	28,3
Ms+120 °C	74,7	25,3

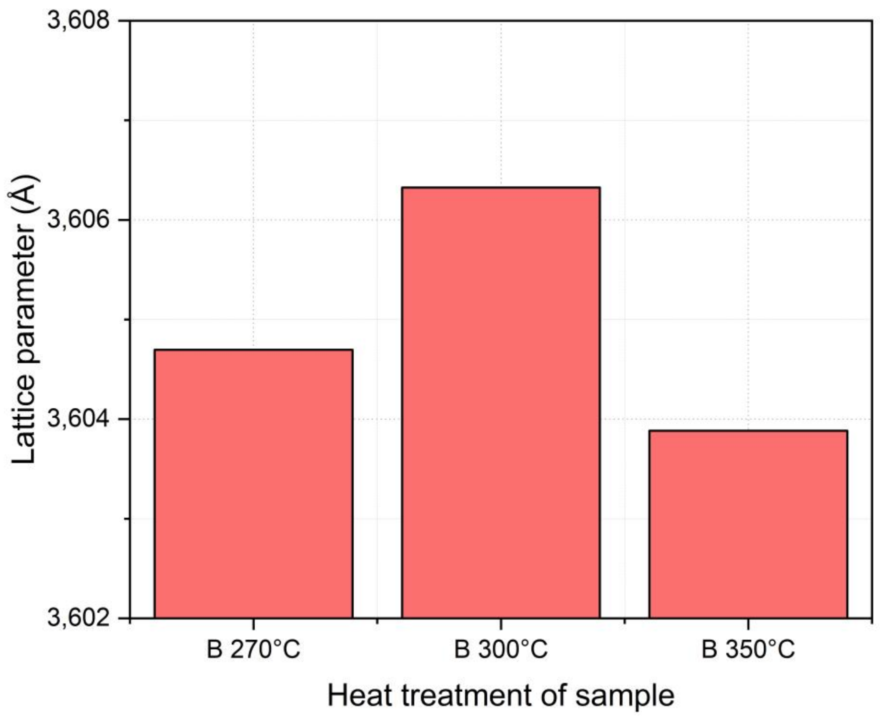
XRD results

EFFECT OF ALLOYING ADDITIONS ON THE LATTICE PARAMETER OF AUSTENITE

D. J. DYSON and B. HOLMES

$$a_0 = 3{\cdot}555 + 0{\cdot}044X \text{Å}$$

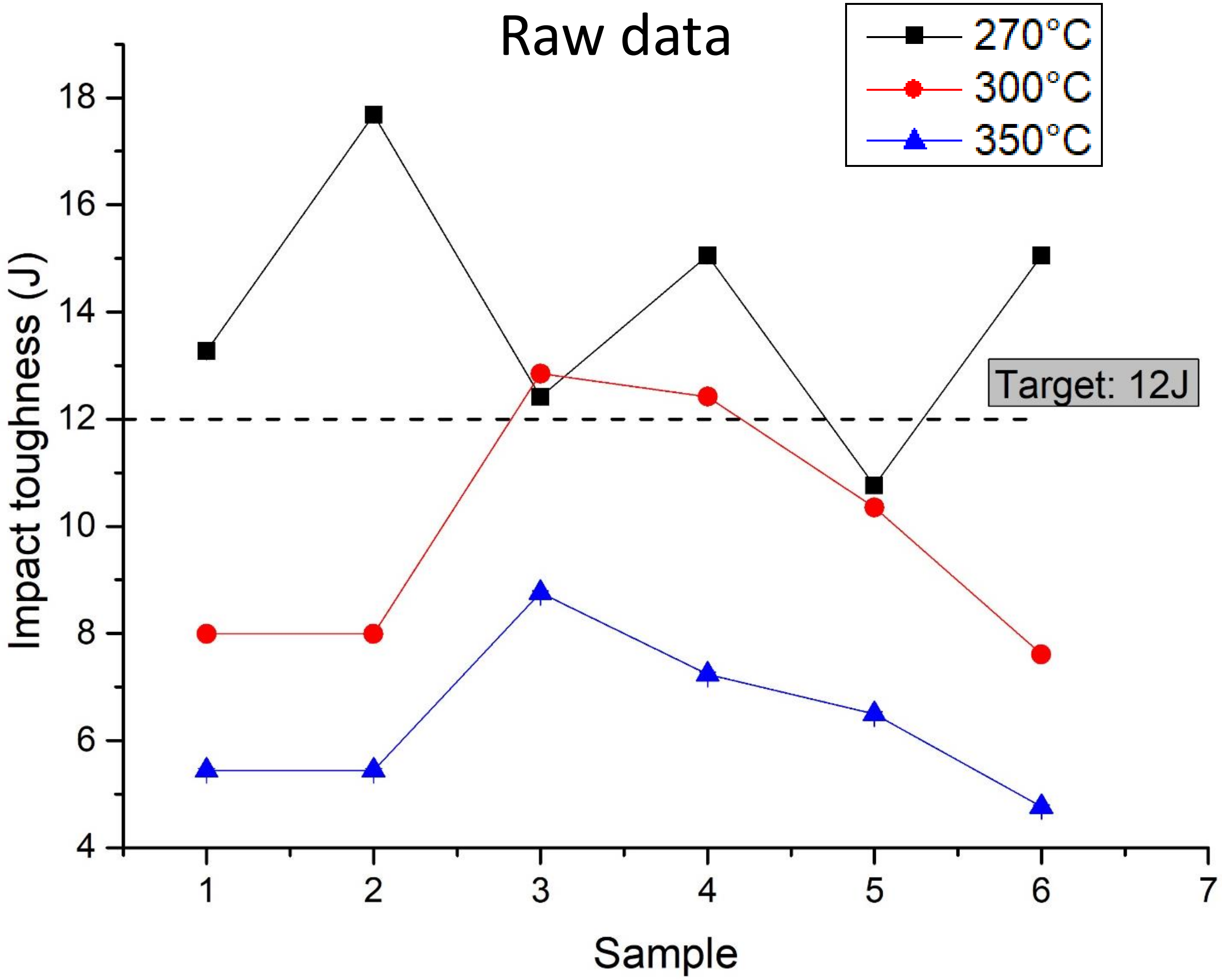
- From the deviation of the theoretical lattice parameter of austenite it is possible to estimate the carbon partitioned from bainite to austenite during bainitizing treatment
- Austenite with more carbon content shows better chemical stability due to the lower Ms temperature



V-notch impact test

Machining technique – EDM (Electrical discharge machining)

V-notch impact test - Results

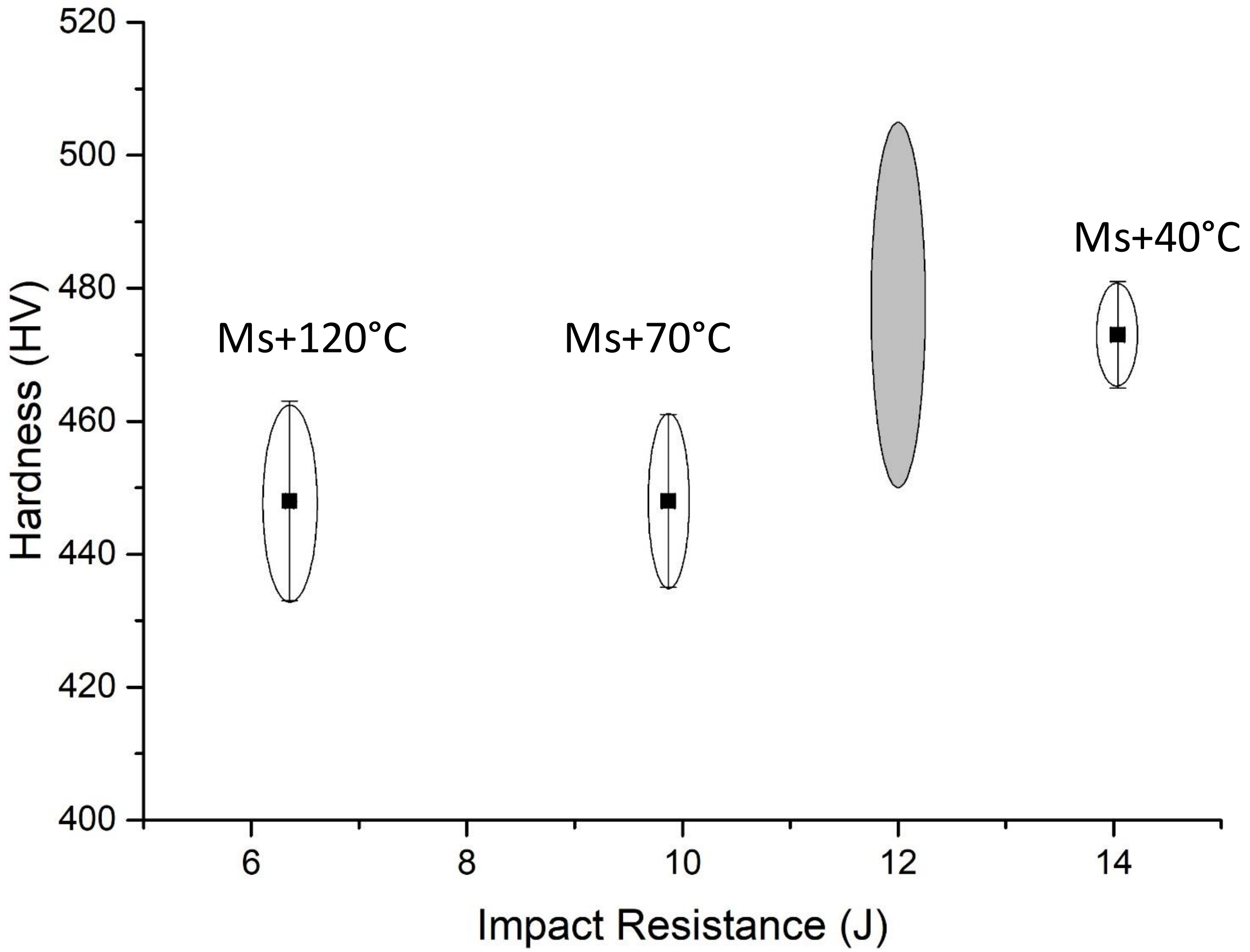


Sample	V-Notch Impact test (J)	
Ms+40°C + T	14,04	± 1,9 *
Ms+70°C + T	9,86	± 1,8 *
Ms+120°C + T	6,35	± 1,2*

* 95% Confidence interval

Results – Mechanical properties

Ashby chart



Conclusions

- Correlating the XRD results (phase fraction and austenite lattice parameters) with the impact resistance of the bainitized samples it is possible to notice that not only a higher volume fraction of retained austenite induces a higher impact resistance.
- The austenite's **chemical** and **mechanical** stability influences the sample's impact properties.
- The enrichment of the retained austenite lower the Ms temperature
- The refinement of the retained austenite increases the mechanical stability
- The more enriched the austenite and refined the structure, the better the combination of hardness and impact resistance of the CFB.
- It was possible to correlate the laboratory scale experiments with pilot scale

Muito obrigado

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