Multiphase-Bainitic Steels

Content

Aims of High Strength Long Products - Project

tensile strength of 900 to 1400 MPa

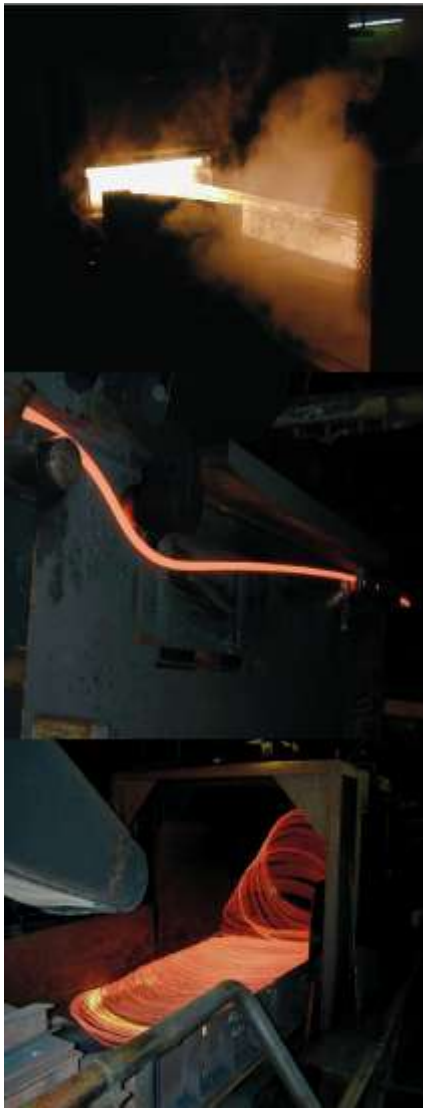
good ductility and toughness ($K_{1C} \approx 150 MNm^{-3/2}$, Charpy V-notch energy ≥ 30 J at -60°C)

develop refined multi-phase microstructures (carbide-free bainite/acicular ferrite with films of retained austenite trapped between the platelets

Aims of High Strength Long Products - Project

Define medium carbon steel compositions
(addition of Si, Mn, Cr, Mo, Ni, V, B)

Aims of High Strength Long Products - Project

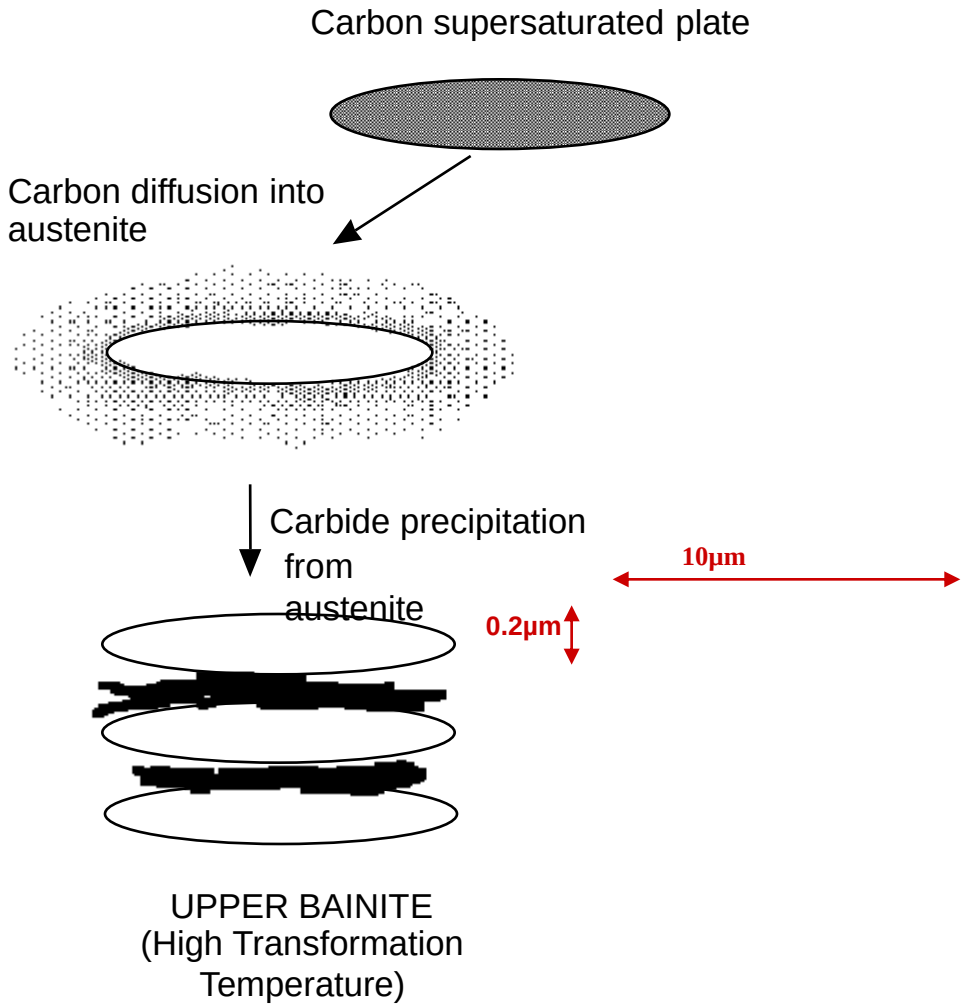


industrial cooling conditions for Long Products (wire rods from 16 to 22mm diameter with cooling rates of 1–4 K/s)

guidelines for the processing parameters (thermomechanical treatment (TMT), austenite conditioning (hot rolling parameters) and cooling strategies (continuous or more-step-cooling)

Content

Upper and Lower Bainite



Upper and Lower Bainite:

•tend to form as aggregates (sheaves) of small platelets or laths (sub-units) of ferrite

•difference:
carbide precipitation

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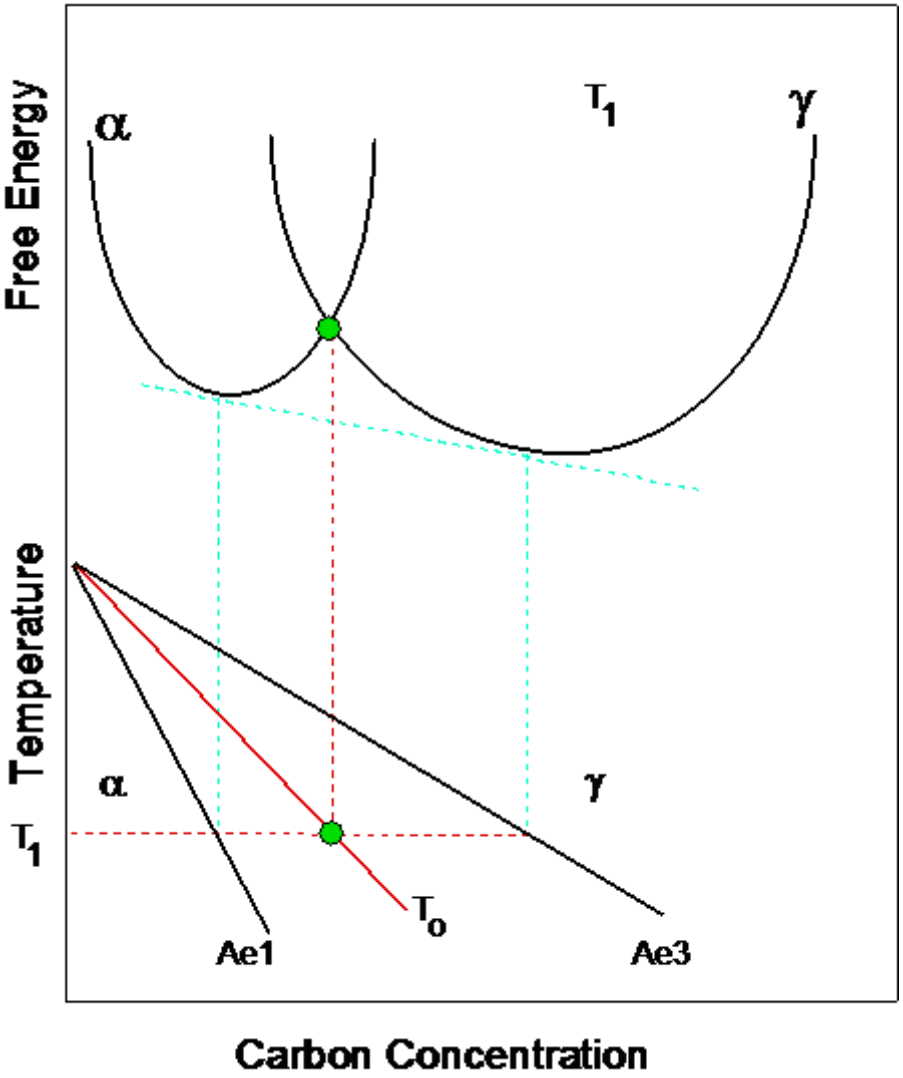
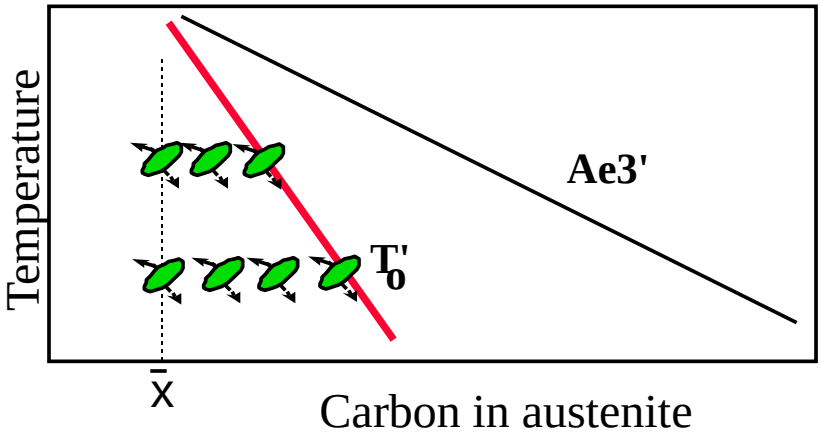
Incomplete Reaction Phenomenon





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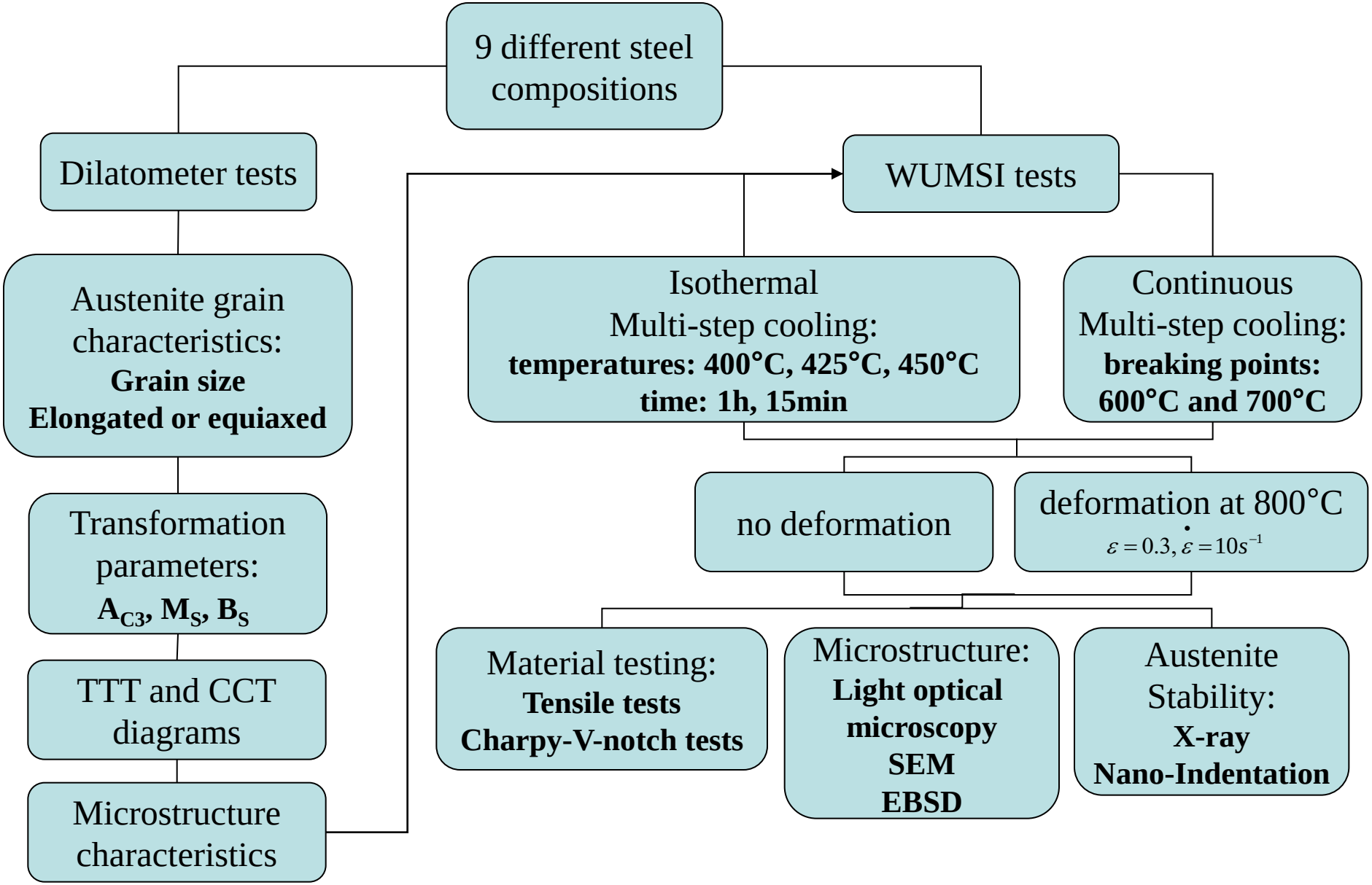
Overview on Proceedings



Chemical analysis of steel compositions

- **Base composition:**
  - ❖ 0.3 wt% **C** - increasing the strength of the steel, stabilizing the austenite
  - ❖ 2.0 wt% **Si** - retarding the carbide precipitation
  - ❖ 1.5 wt% **Mn** - stabilizing the austenite

- **Additional alloying elements:**
  - ❖ **Cr**, **Mo**, **Ni**, **V**, **B** and **P** – influence the trans-formation (inhibit diffusional, promote bainitic transformation)

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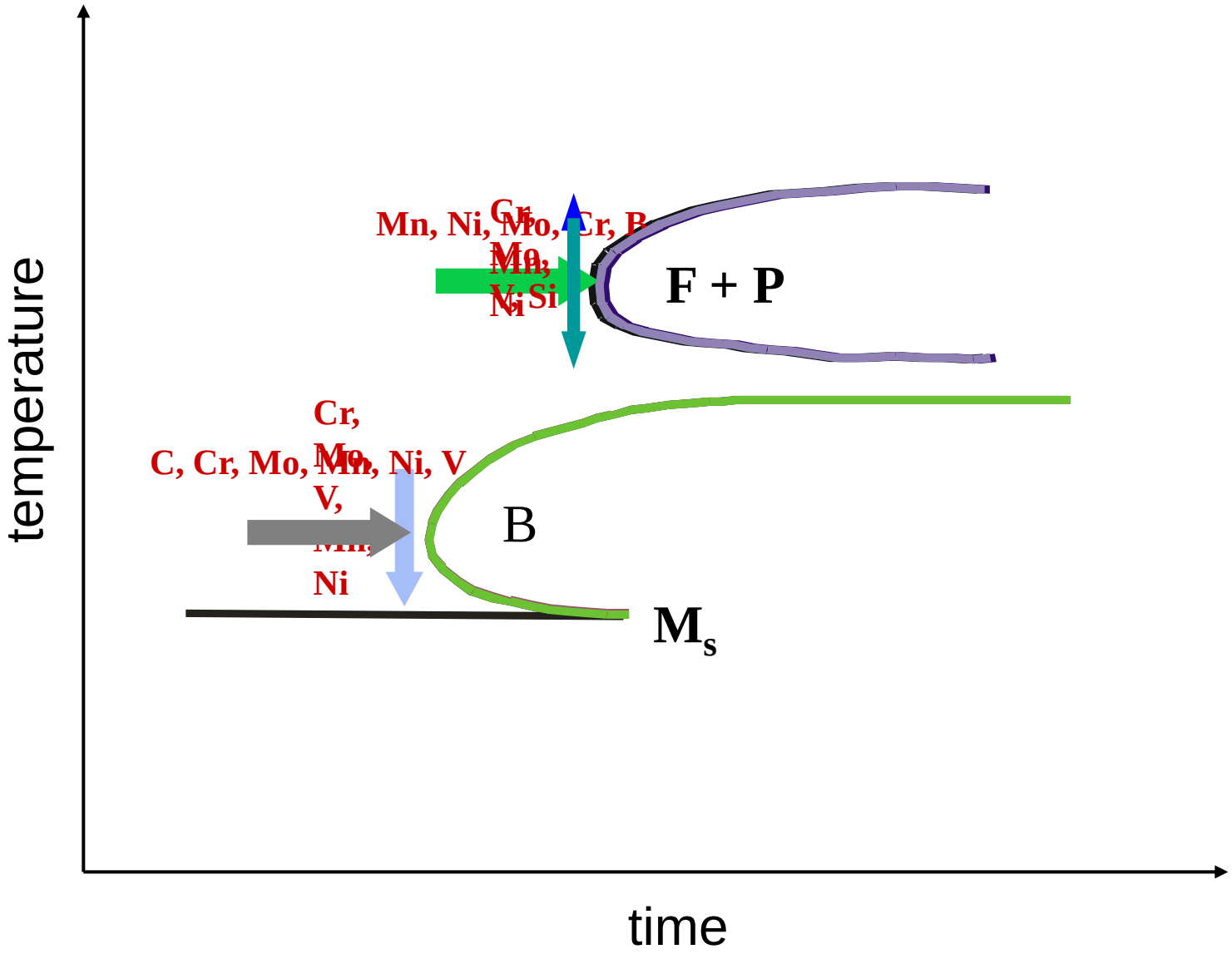
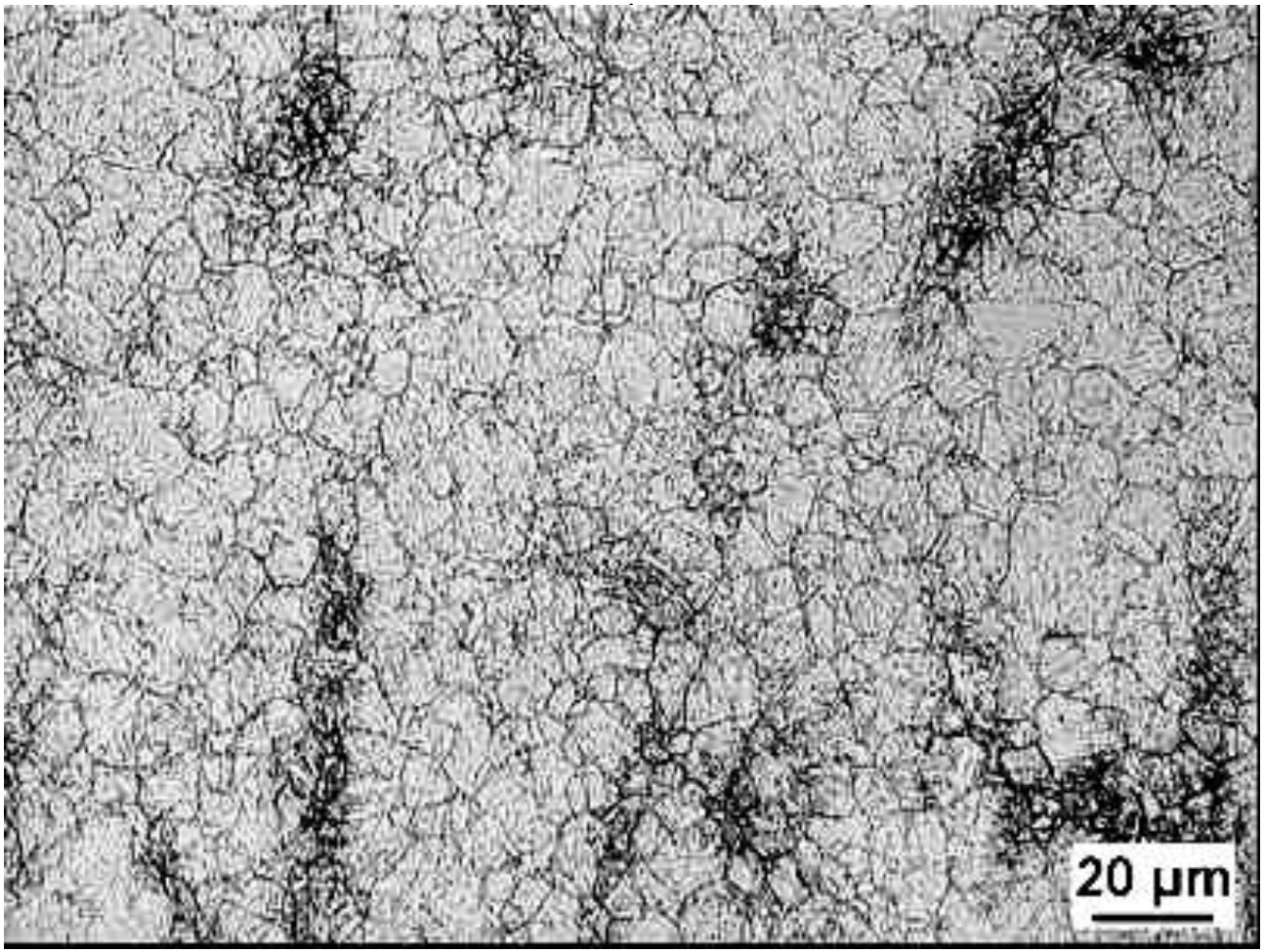
Influence of alloying elements on transformation



Content

Austenizing, tempering and etching tests



Variation of:

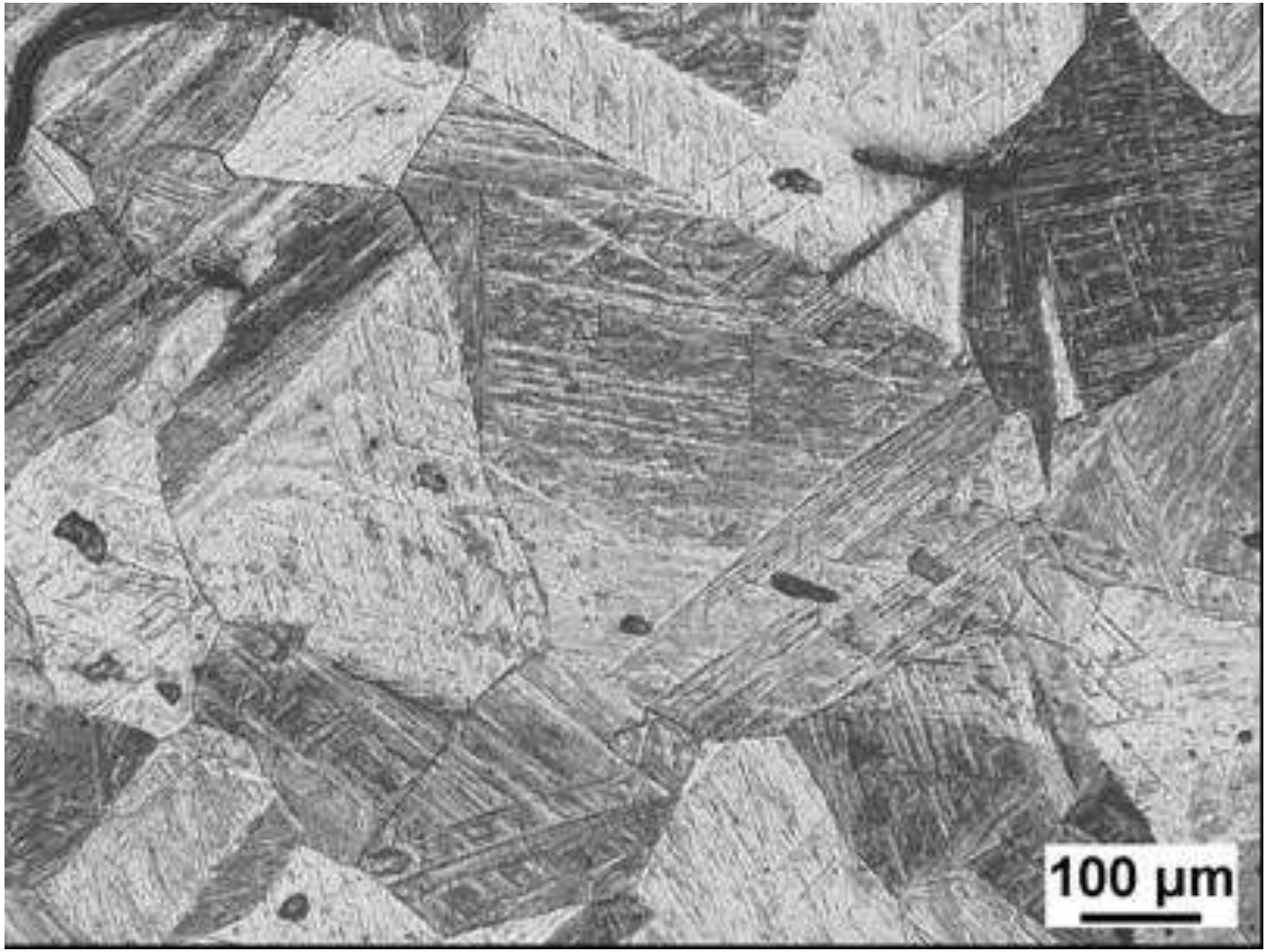
$T_{austen.}$ = 950°C-1200°C

T_{temper} = 300°C-600°C

Etchant: aqueous or alcoholic picric acid + Cu2Cl at room temperature or heated at 80°C; alcoholic nitric acid; mixture of nitric acid and picric acid + Cu2Cl

MP_MnSi: $T_{austen.}$= 950°C; T_{temper}= 450°C, aqueous picric acid; G = 11-12

Thermal etching



MP_CrMoNi:

$T_{austen.}$ = 1200°C

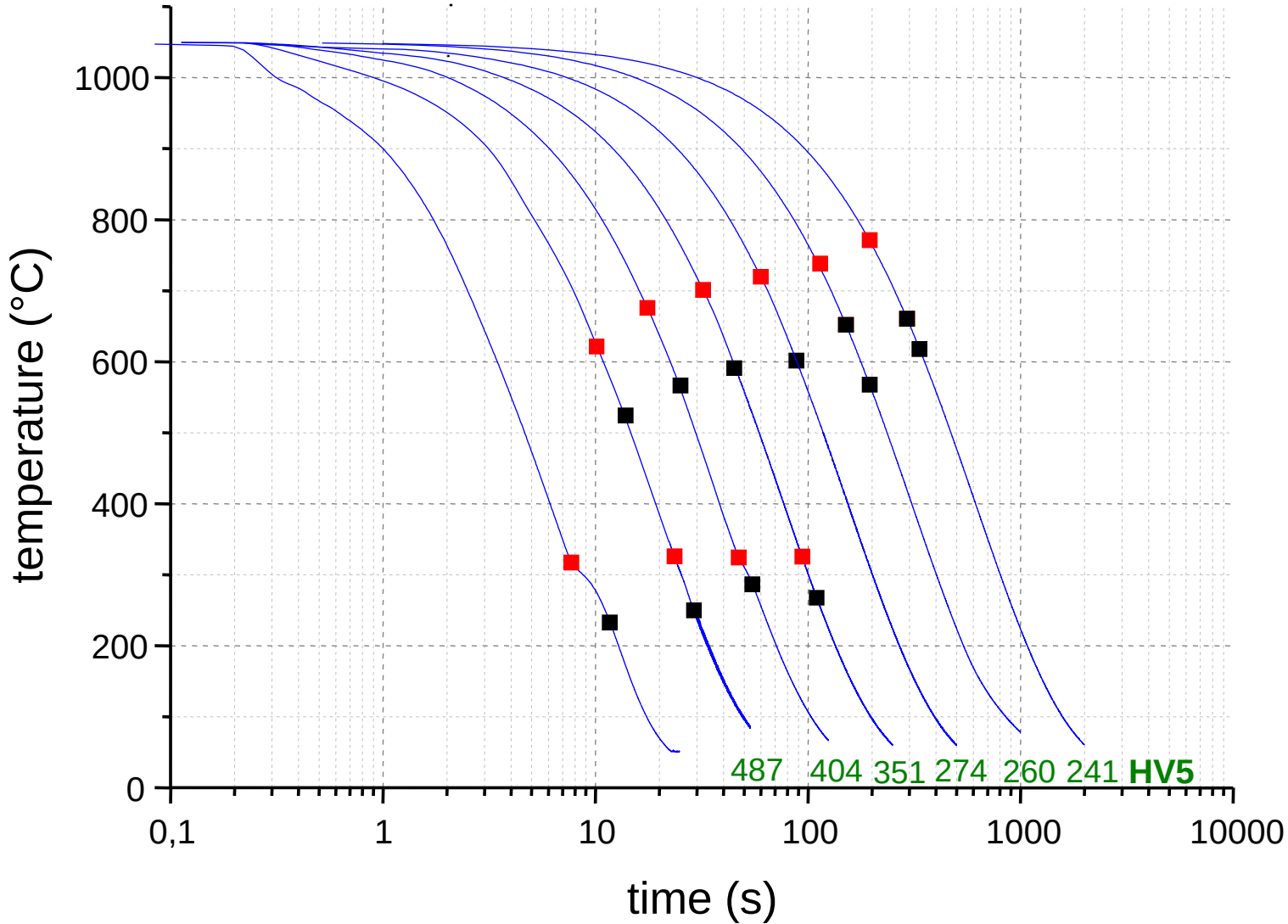
Thermal etching

G = 2-3

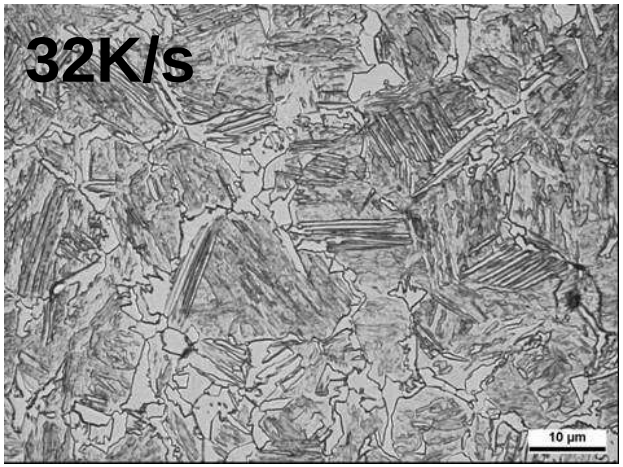
Content

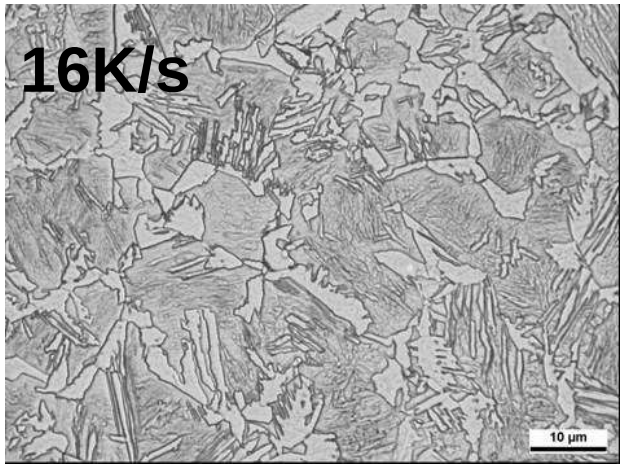
Determination of CCT-diagrams without deformation

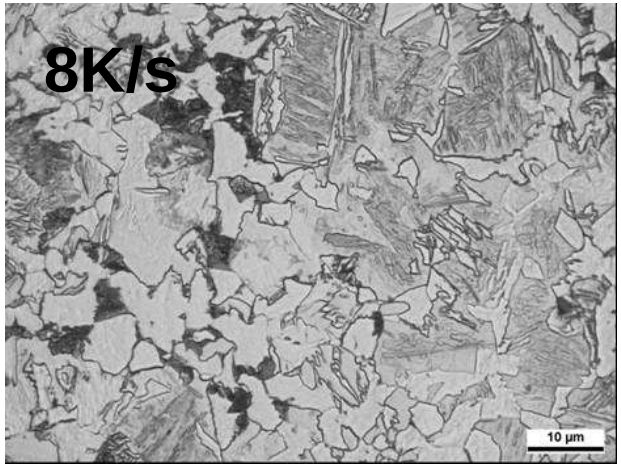
Steel	Base of chemical composition (wt%)							Additional alloying elements (wt%)				
	C	Mn	Si	S	P	Al	N	Cr	Mo	Ni	V	B
MP_MnSi	0.3	1.5	2.0	0.0135	0.0110	0.04	0.005	-	-	-	-	-

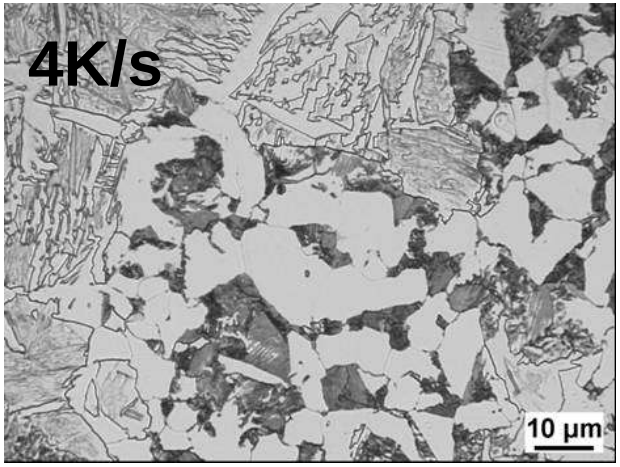


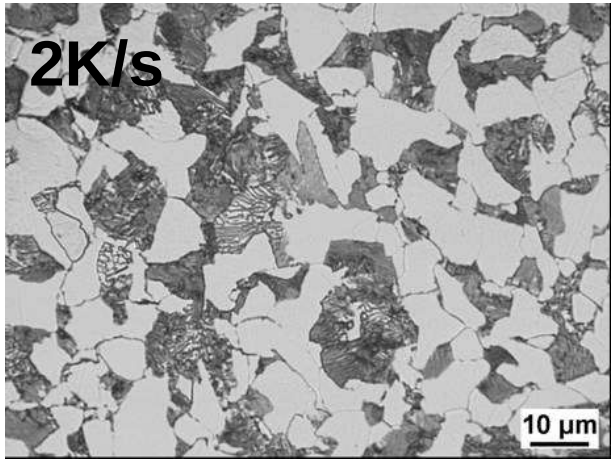
MP_MnSi, 32K/s to 1K/s

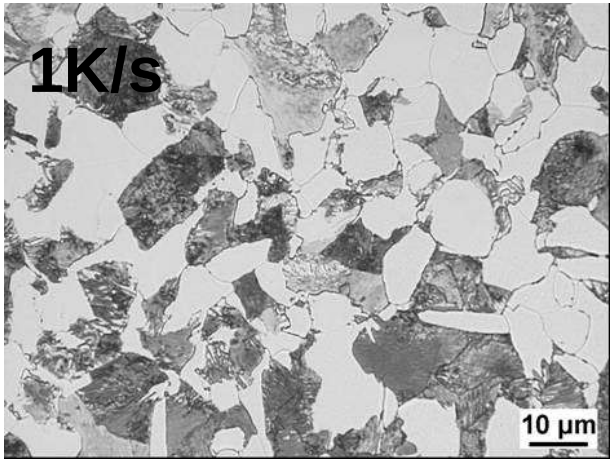






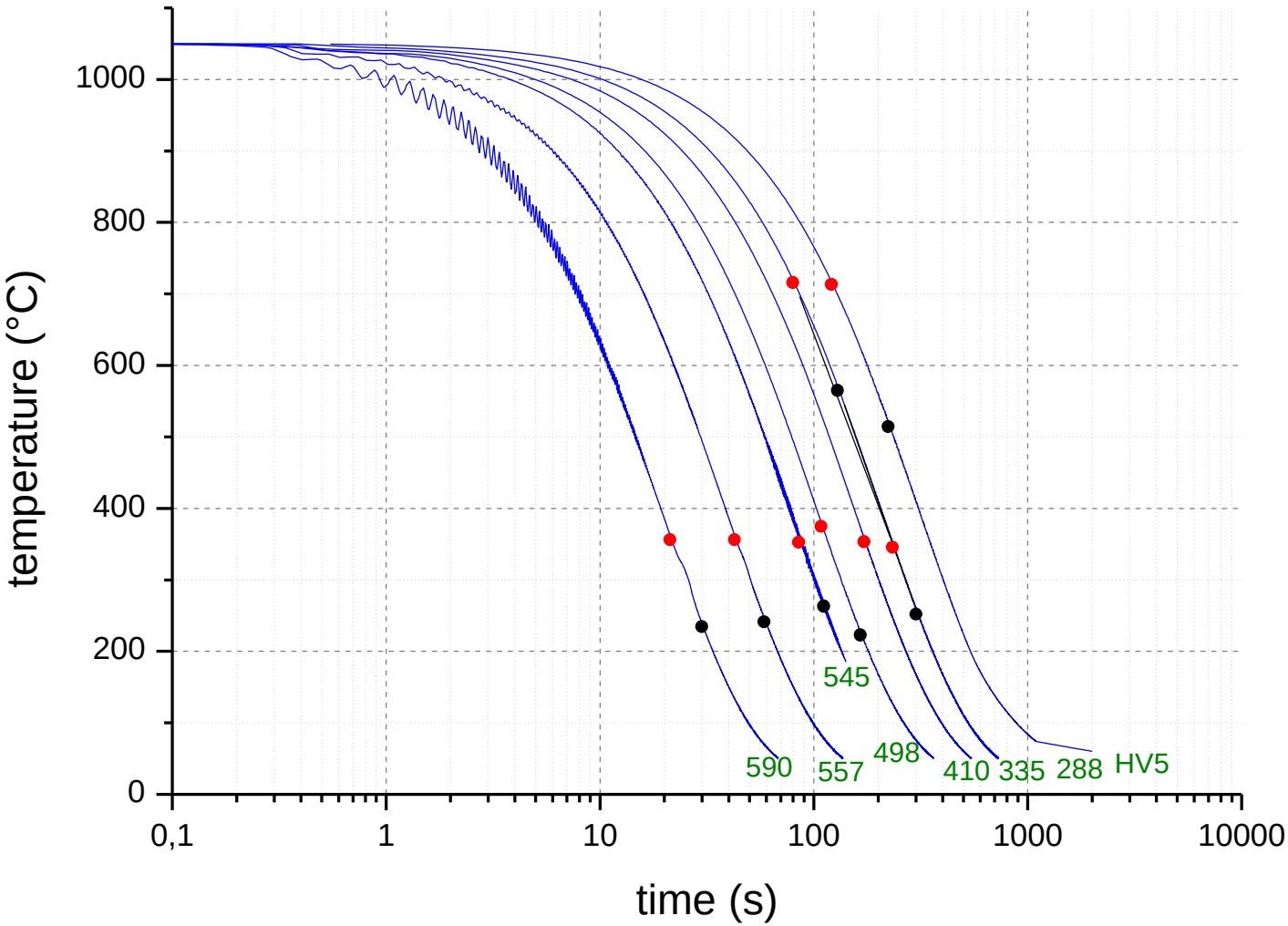




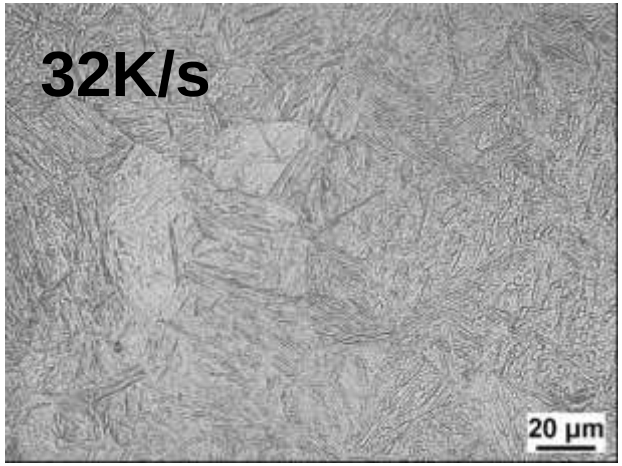


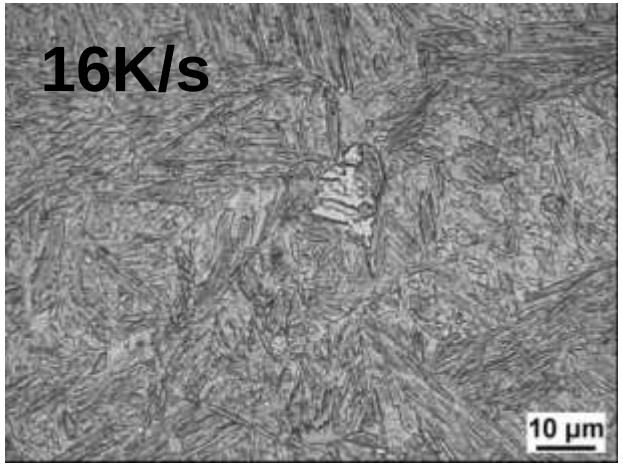
Determination of CCT-diagrams without deformation

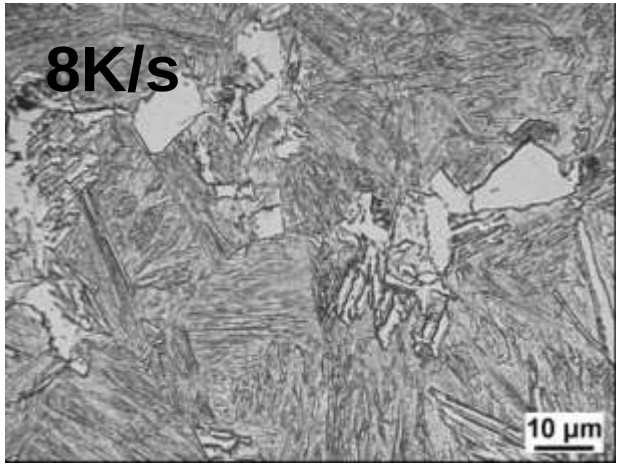
Steel	Base of chemical composition (wt%)							Additional alloying elements (wt%)				
	C	Mn	Si	S	P	Al	N	Cr	Mo	Ni	V	B
MP_B	0.3	1.5	2.0	0.0135	0.0110	0.04	0.005	-	-	-	-	< 20ppm

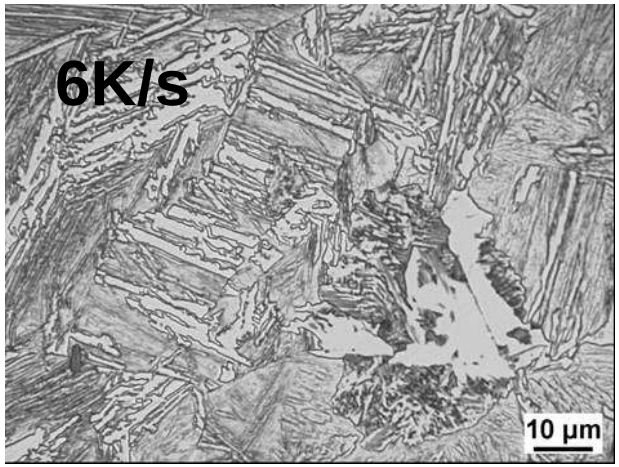


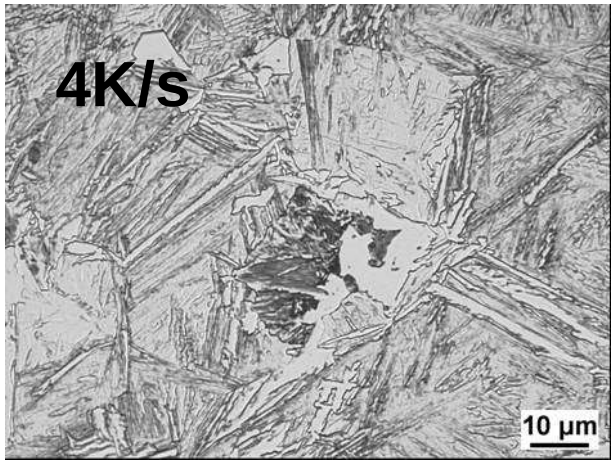
MP_B, 32K/s to 3K/s

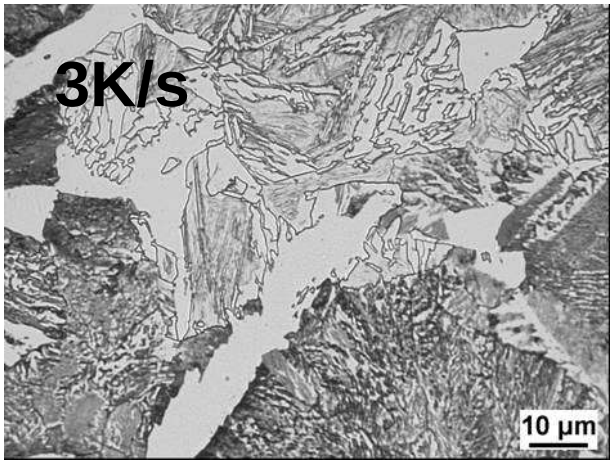






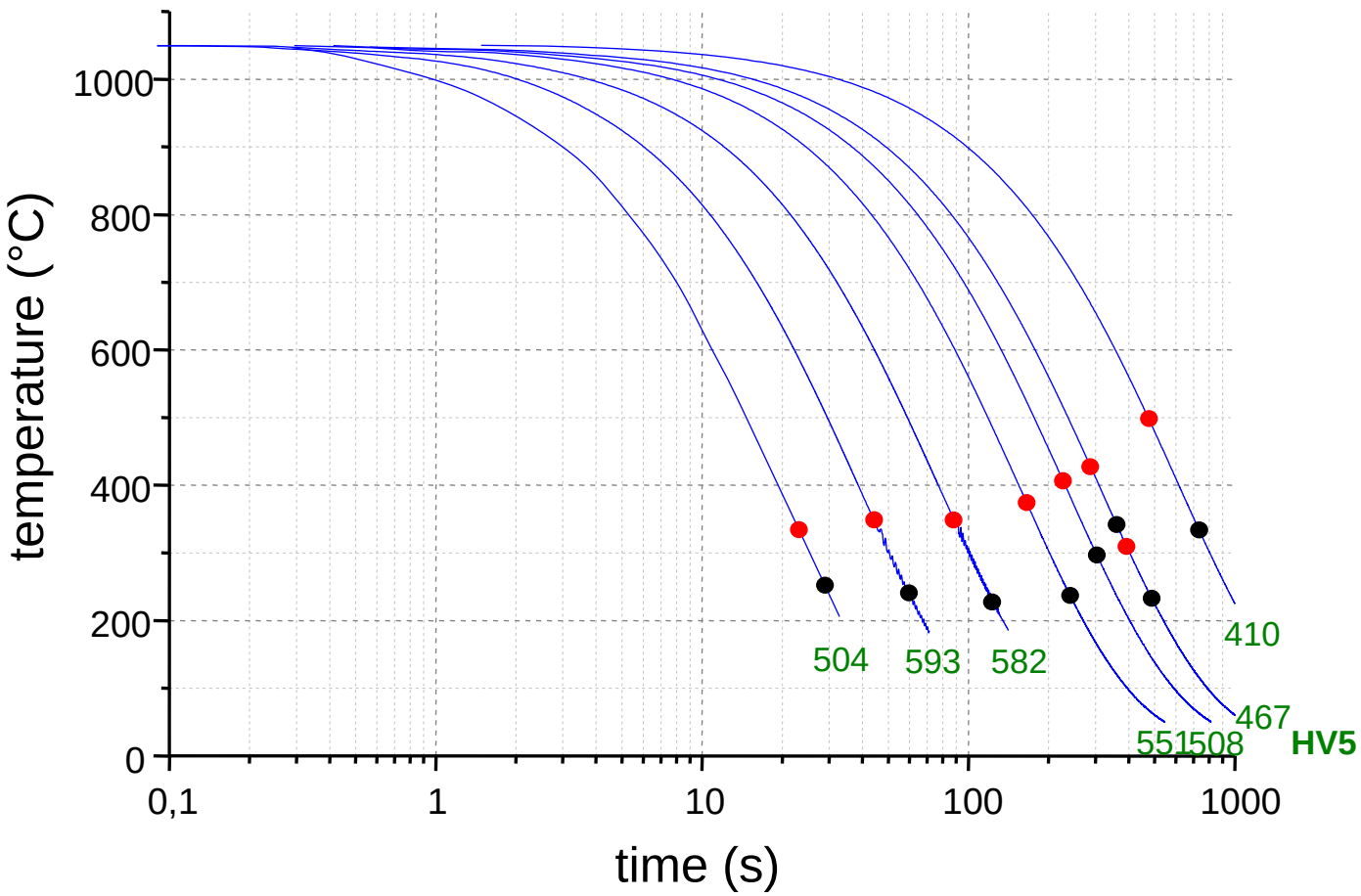




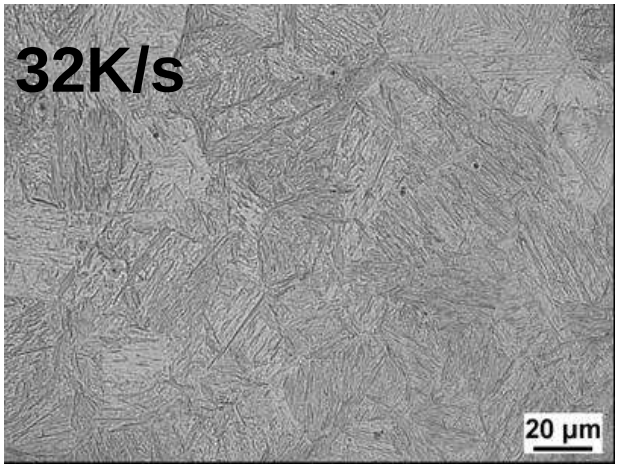


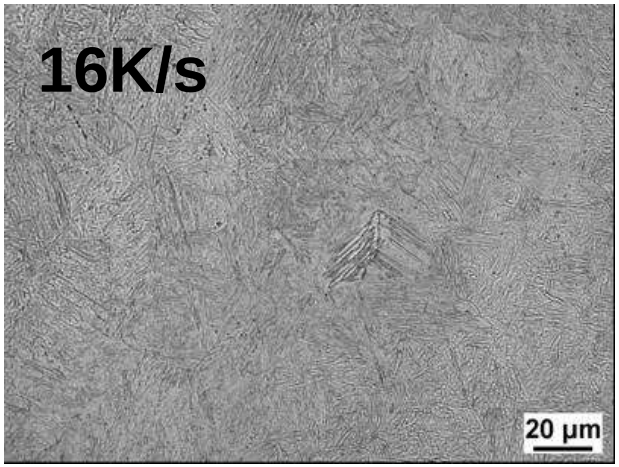
Determination of CCT-diagrams without deformation

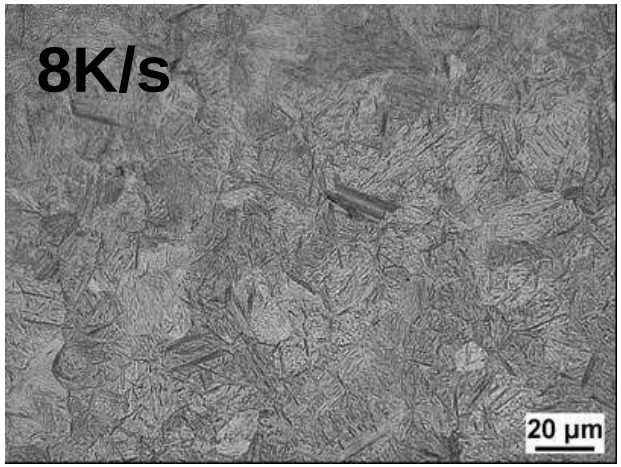
Steel	Base of chemical composition (wt%)							Additional alloying elements (wt%)				
	C	Mn	Si	S	P	Al	N	Cr	Mo	Ni	V	B
MP_Mo	0.3	1.5	2.0	0.0135	0.0110	0.04	0.005	_	0.6	_	_	-

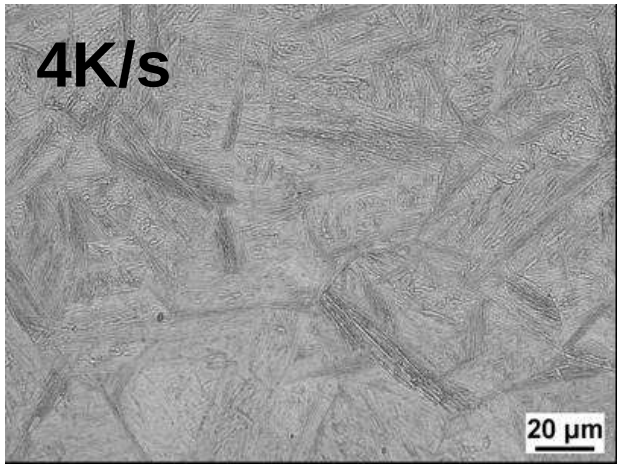


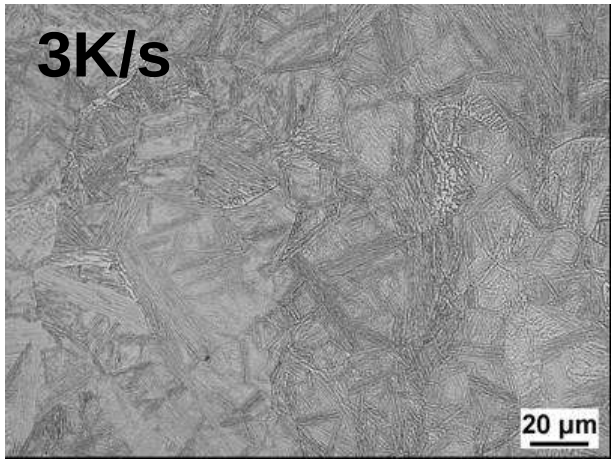
MP_Mo, 32K/s to 2K/s

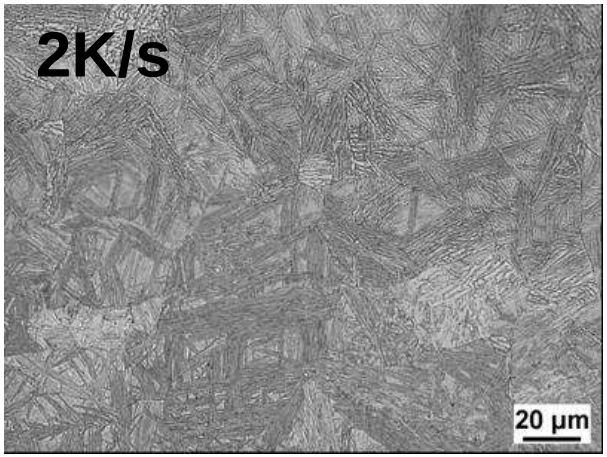




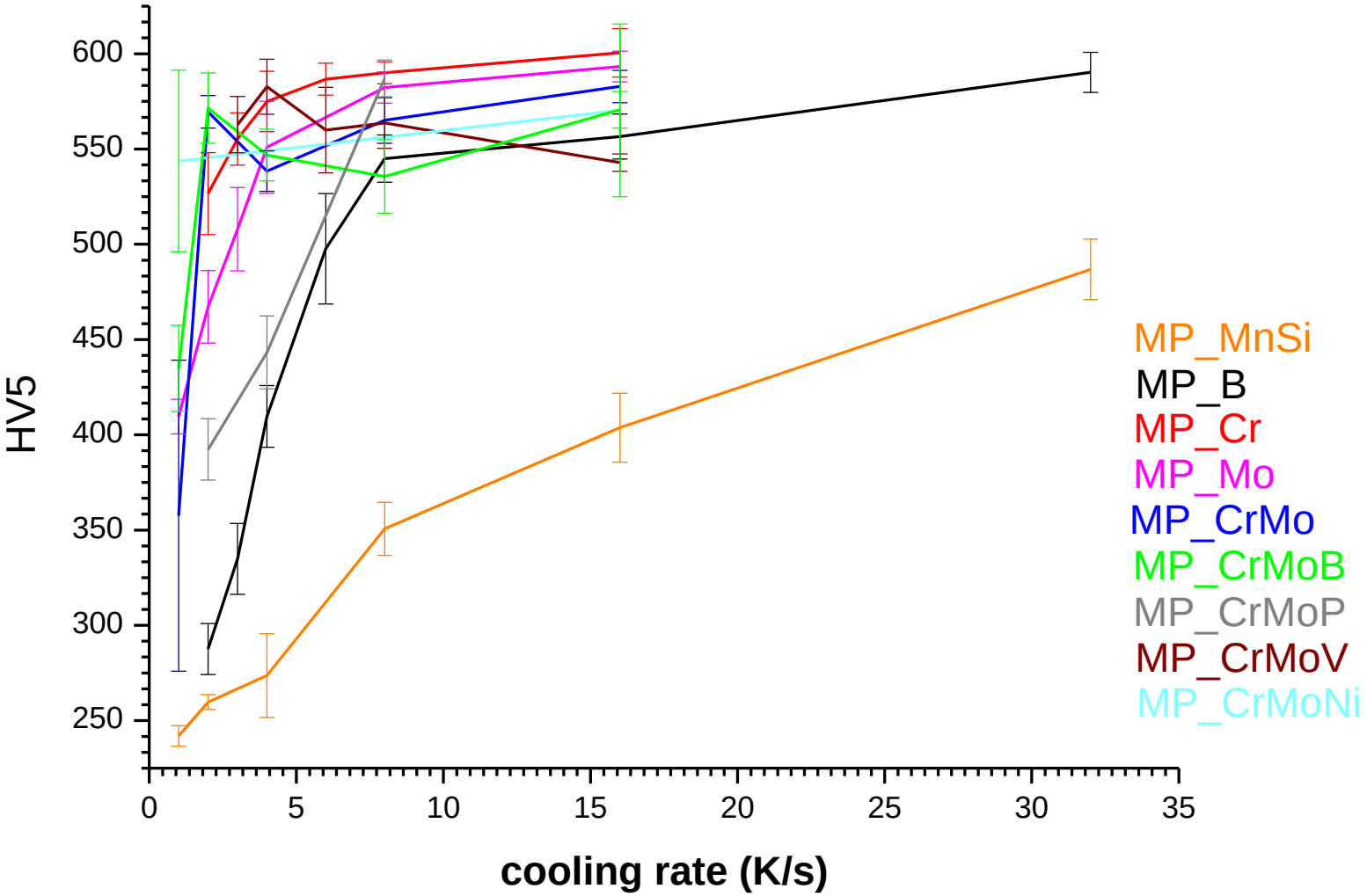








Hardness (HV5) of continuous cooled samples



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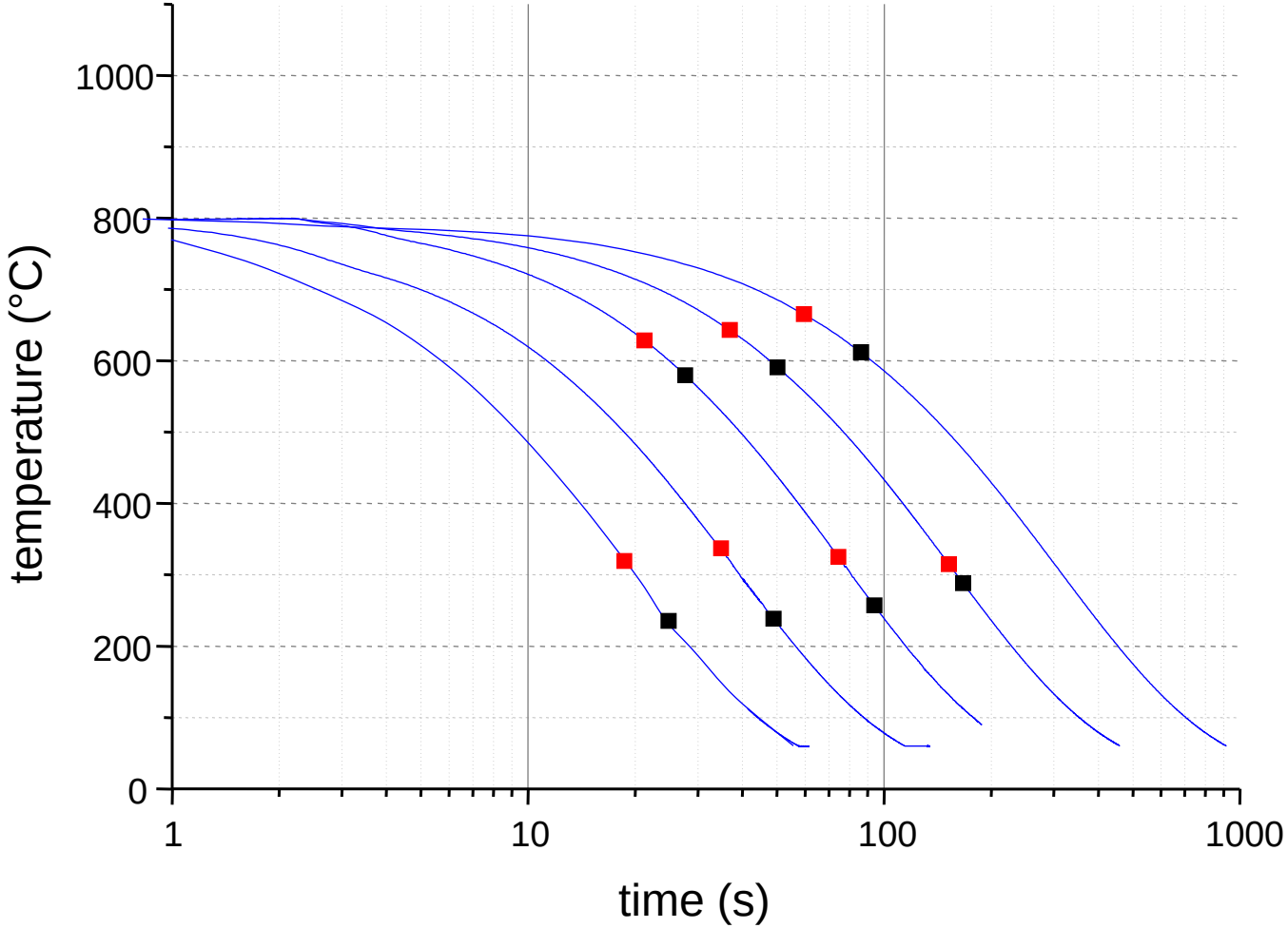
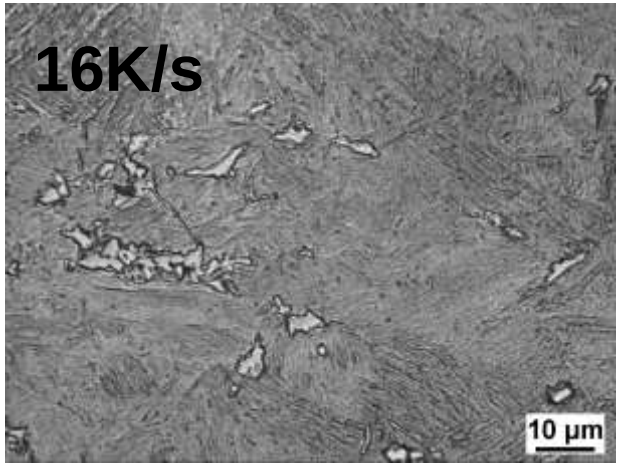
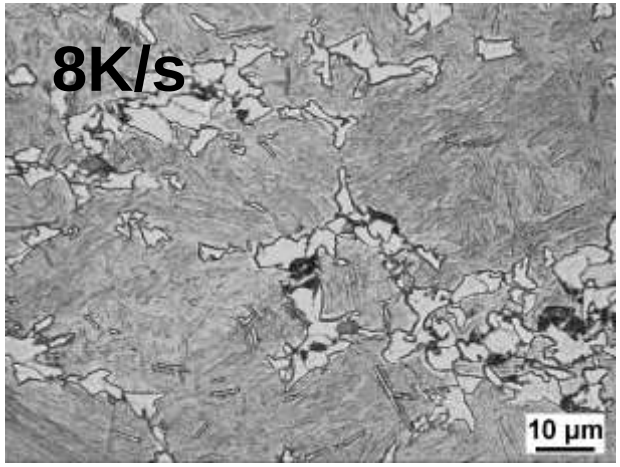
Determination of CCT-diagrams with deformation

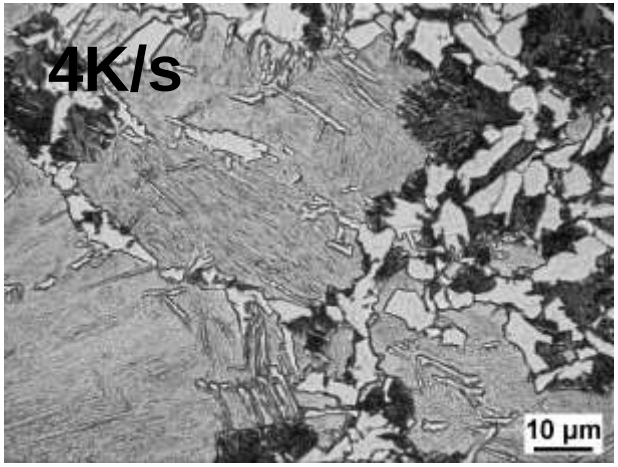
Steel	Base of chemical composition (wt%)							Additional alloying elements (wt%)				
	C	Mn	Si	S	P	Al	N	Cr	Mo	Ni	V	B
MP_B	0.3	1.5	2.0	0.0135	0.0110	0.04	0.005	-	-	-	-	<20ppm



MP_B, 32K/s to 2K/s

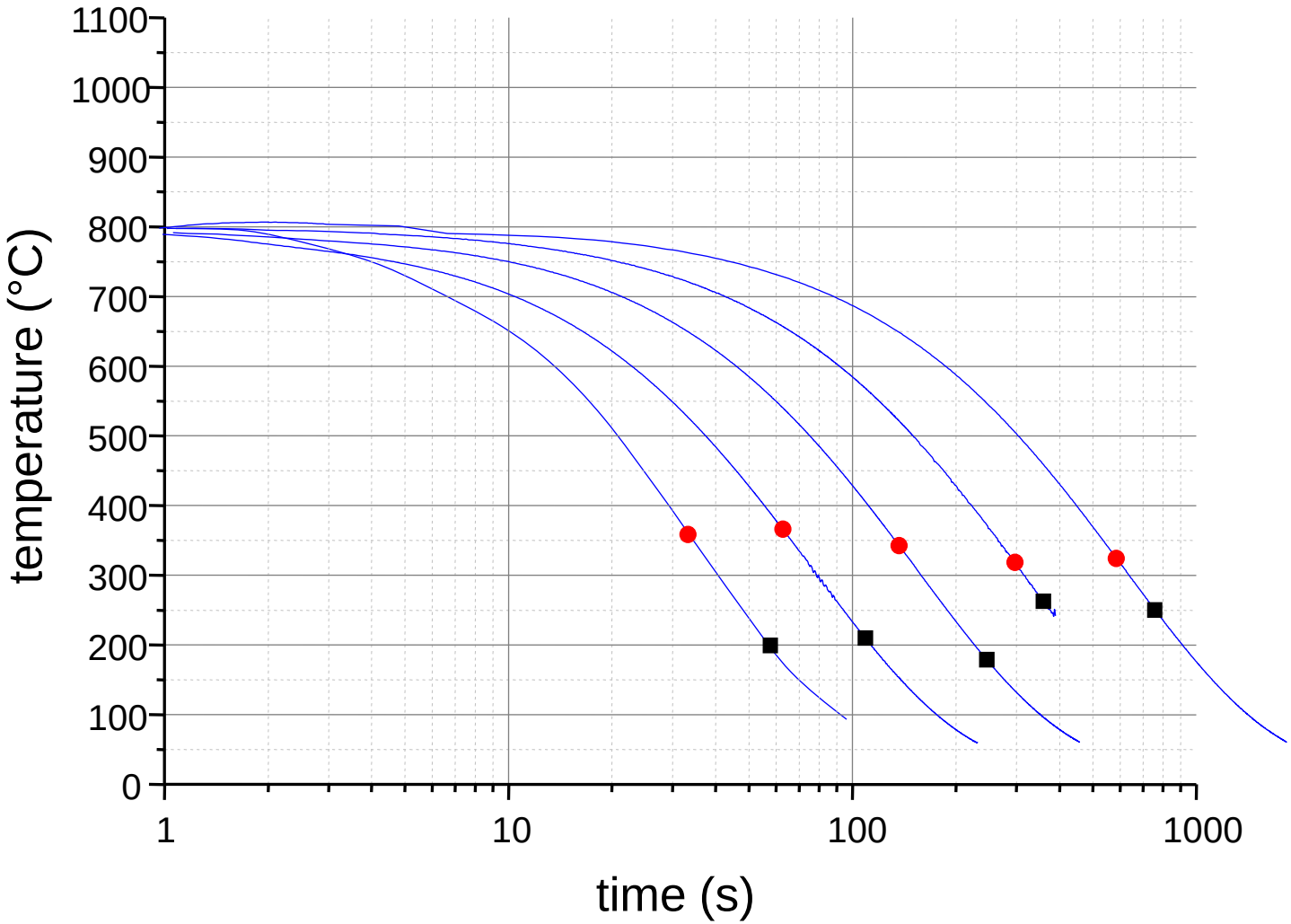




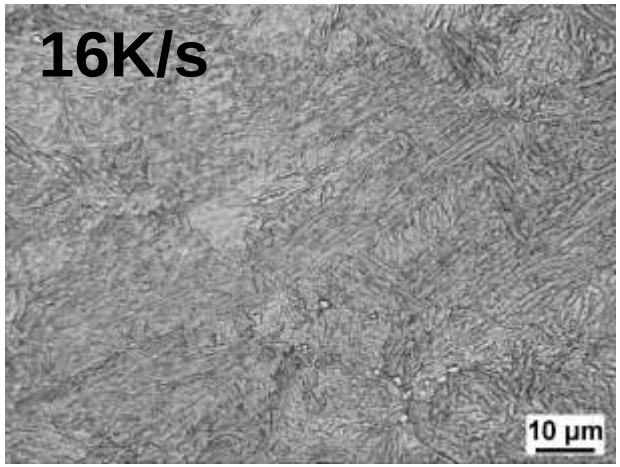


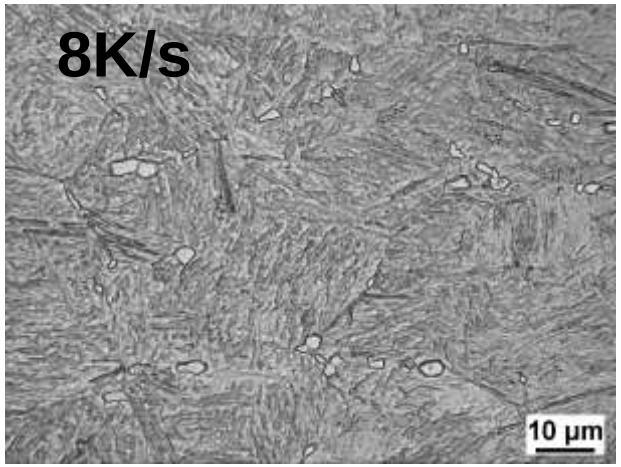
Determination of CCT-diagrams with deformation

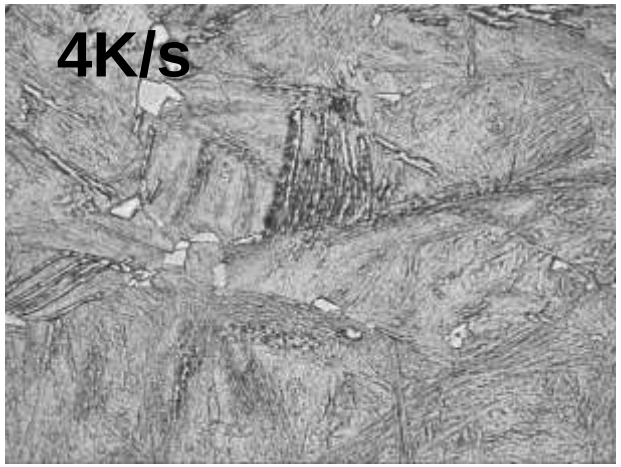
Steel	Base of chemical composition (wt%)							Additional alloying elements (wt%)				
	C	Mn	Si	S	P	Al	N	Cr	Mo	Ni	V	B
MP_Mo	0.3	1.5	2.0	0.0135	0.0110	0.04	0.005	-	0.6	-	-	-



MP_Mo, 16 K/s to 4 K/s

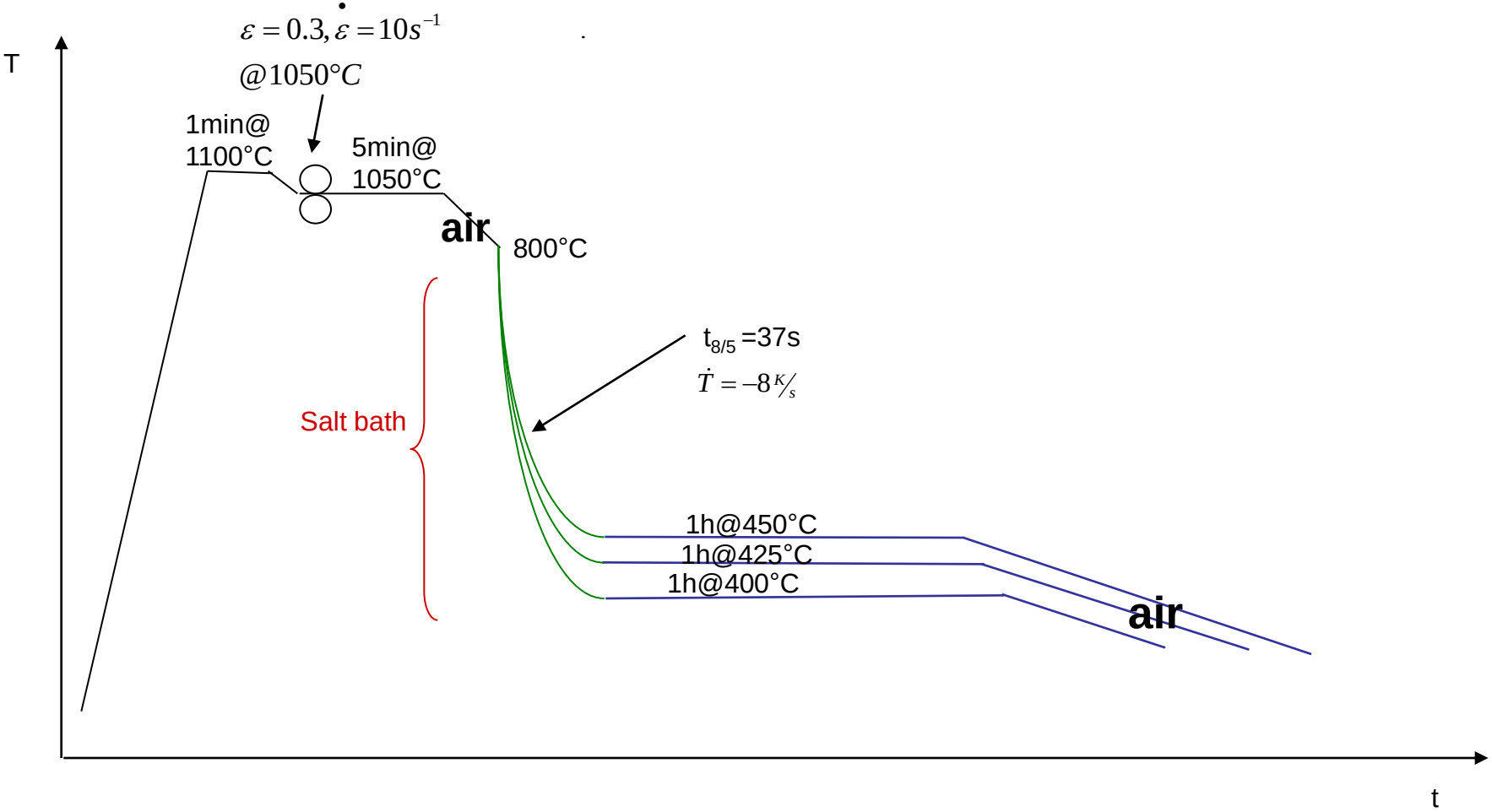




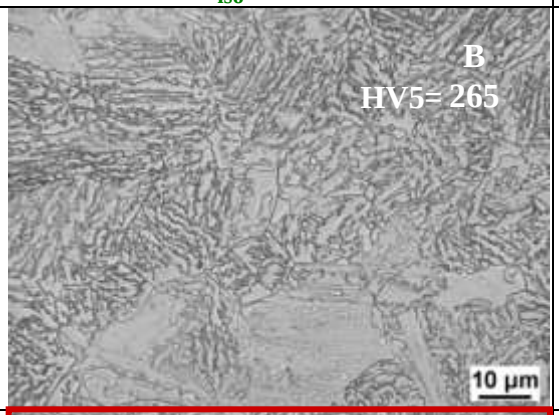
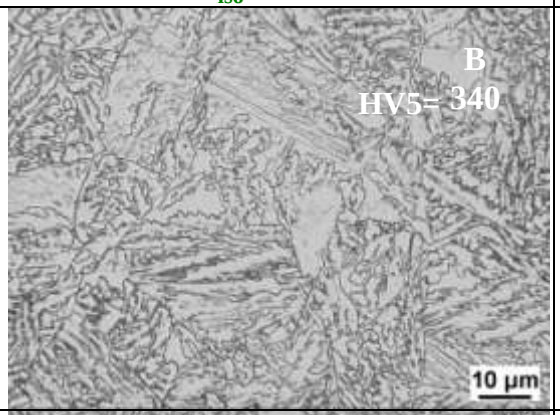
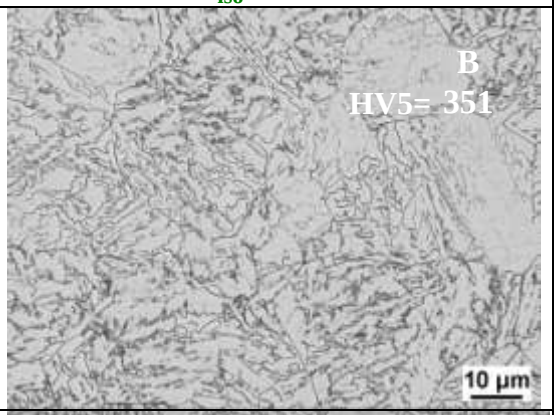
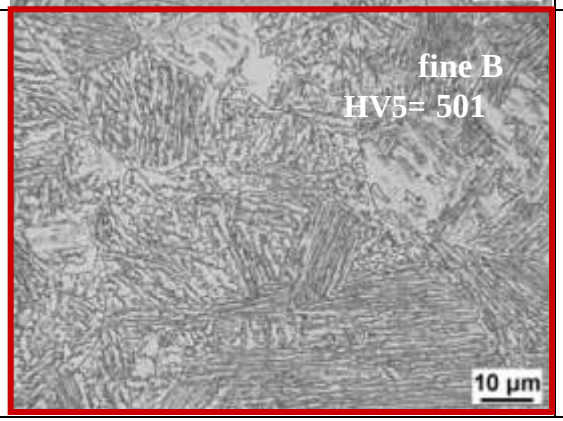
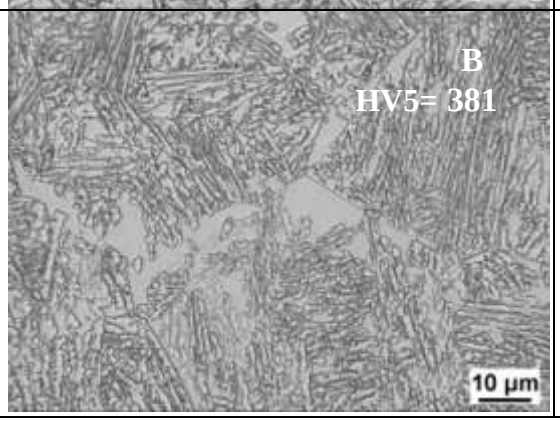
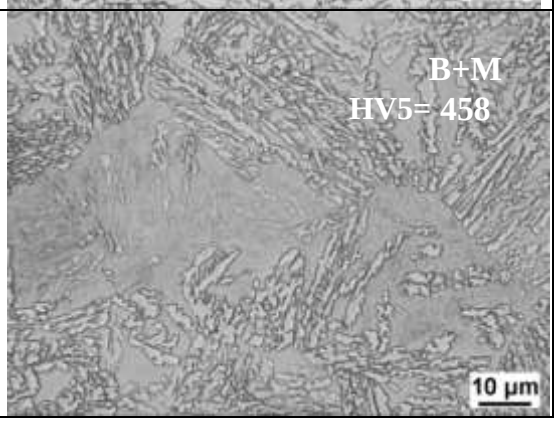


Content

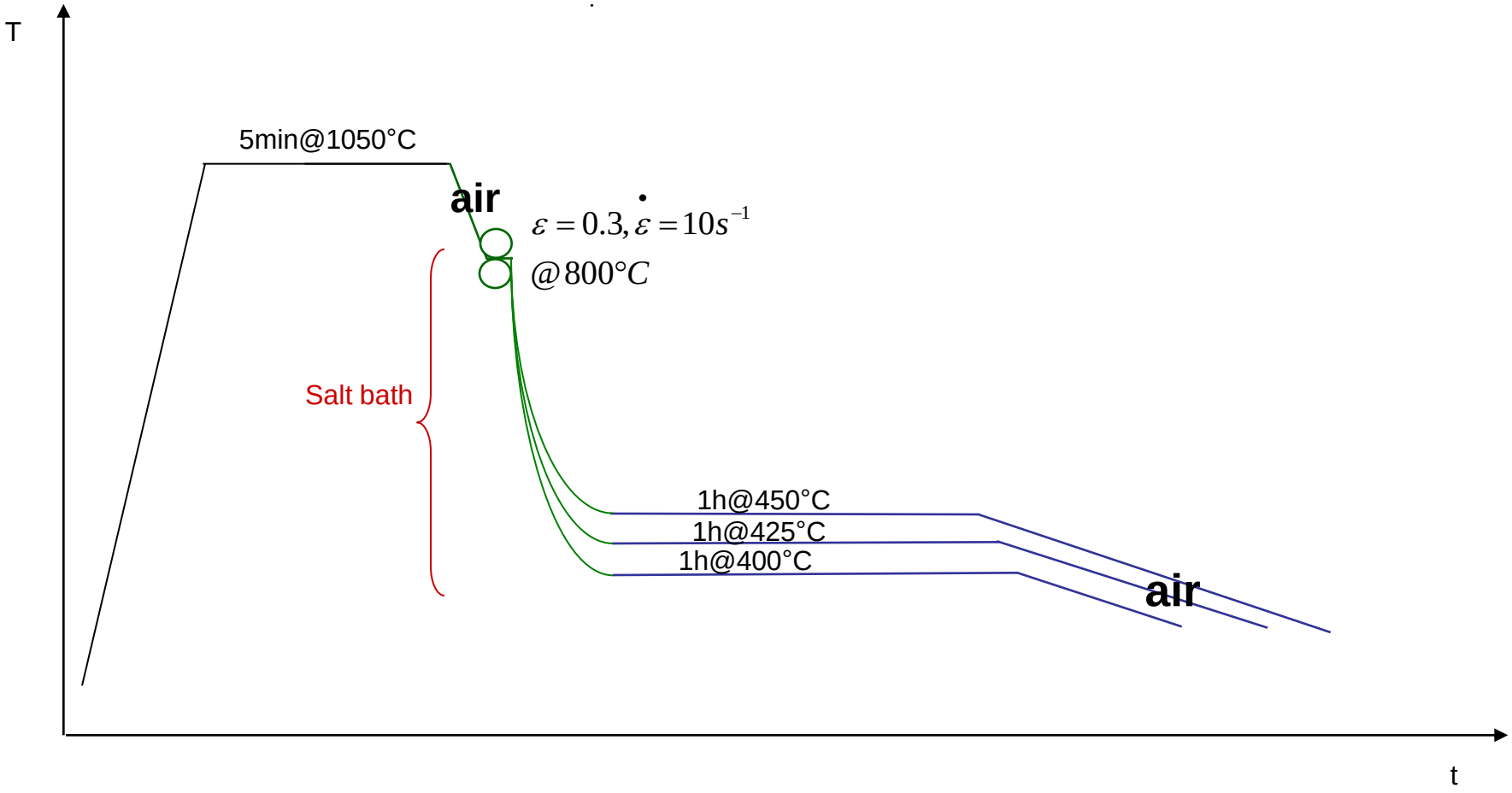
WUMSI (isothermal tests, without deformation)



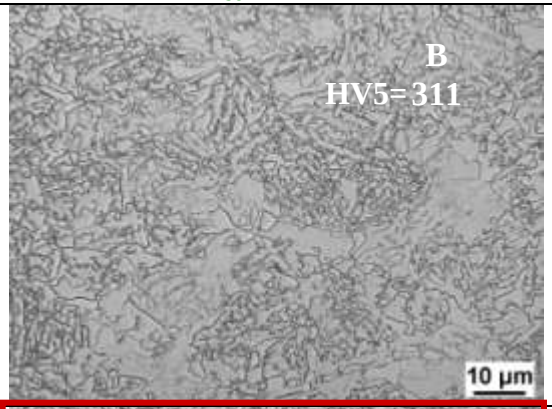
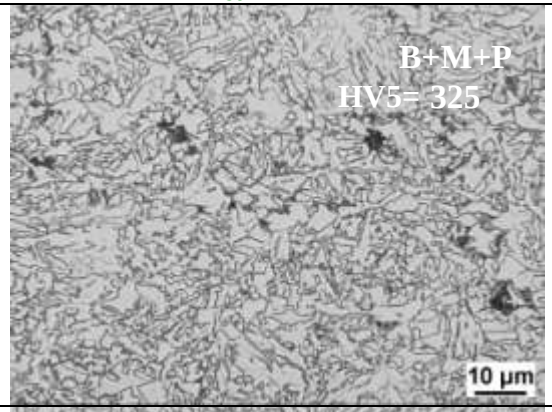
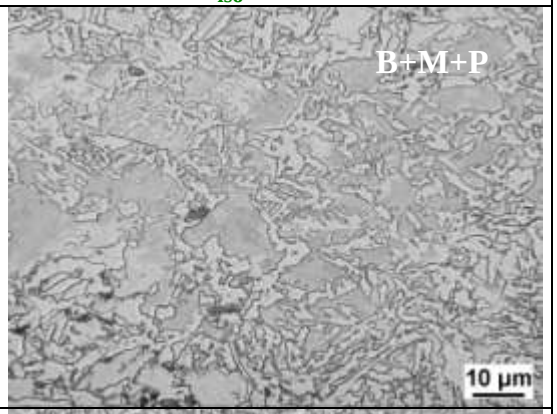
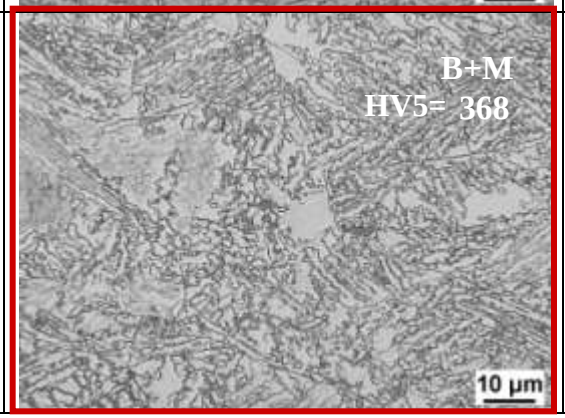
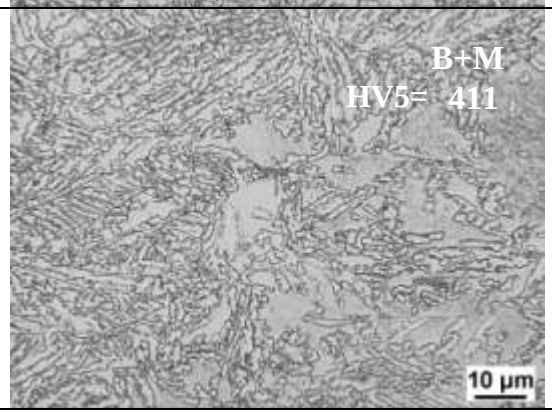
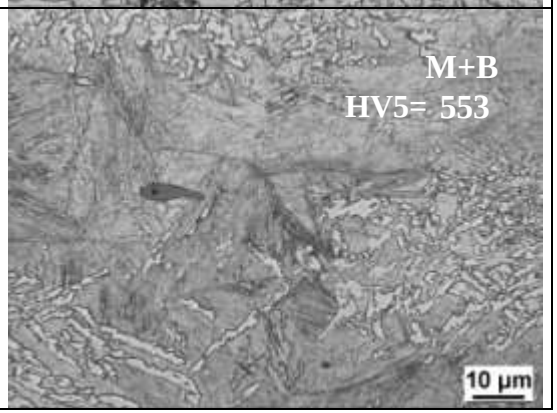
WUMSI (isothermal holding 1h, without deformation)

Steel	Without deformation		
	T_{iso}=400°C	T_{iso}=425°C	T_{iso}=450°C
MP_B			
MP_Mo			

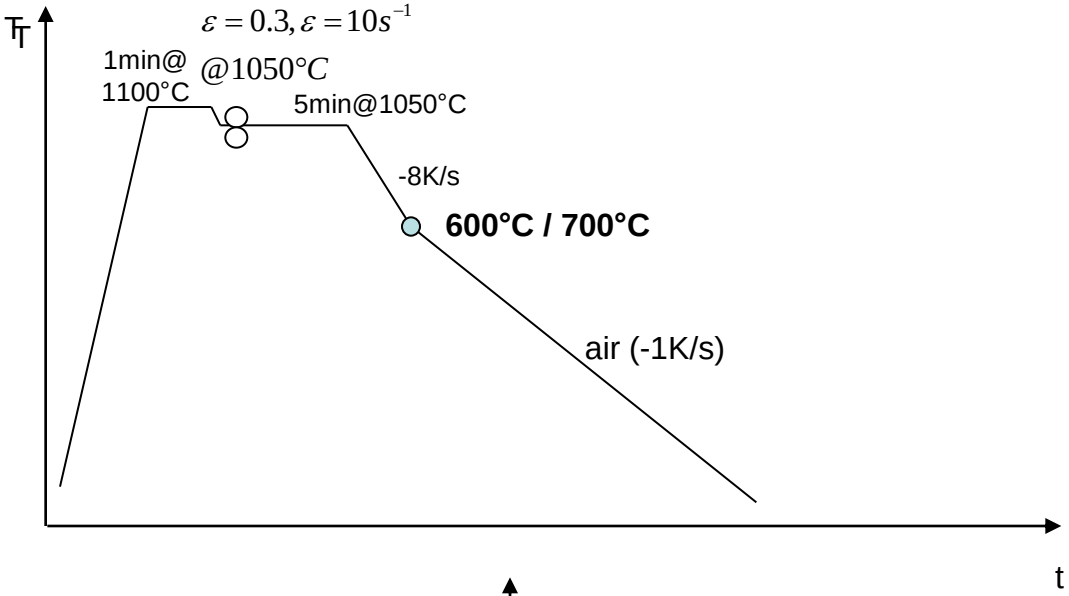
WUMSI (isothermal tests, with deformation)

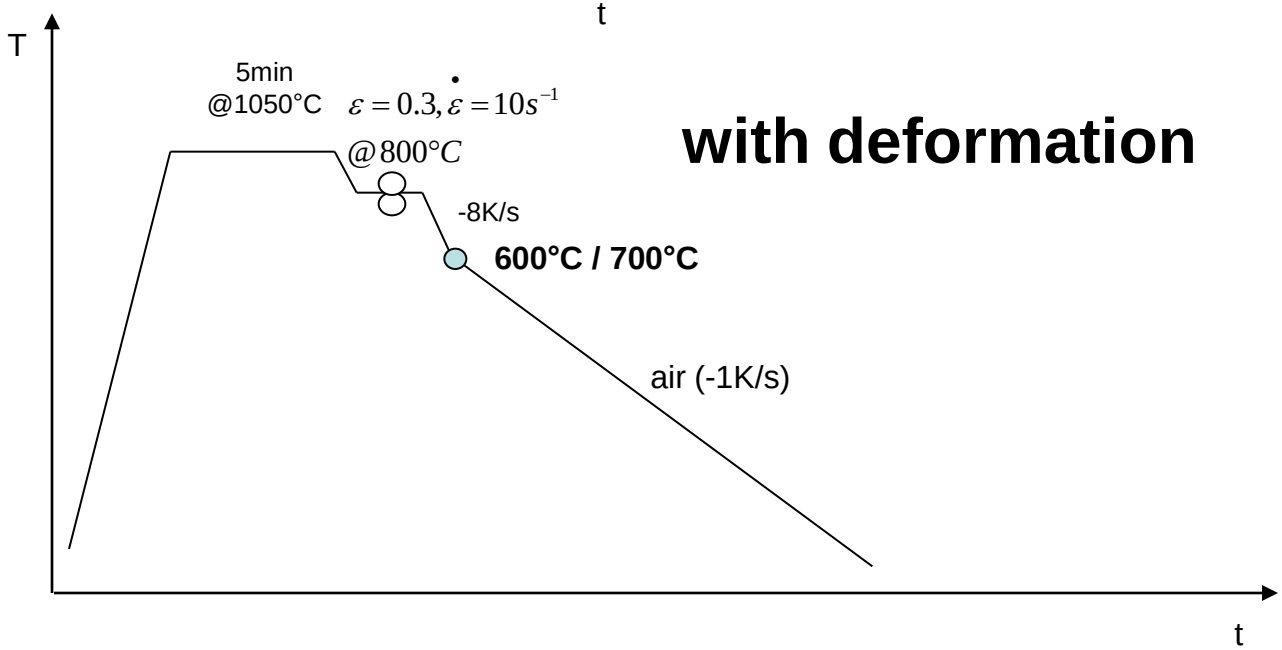


WUMSI (isothermal holding 1h, with deformation)

Steel	With Deformation (0.3; $10s^{-1}$ @800°C)		
	T_{iso}=400°C	T_{iso}=425°C	T_{iso}=450°C
MP_B			
MP_Mo			

WUMSI (Continuous cooling)

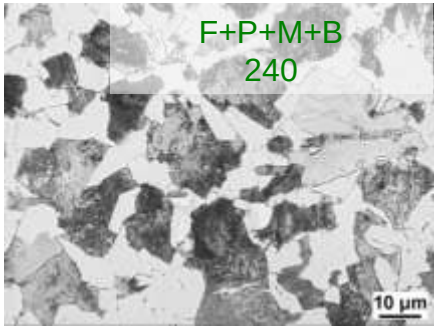
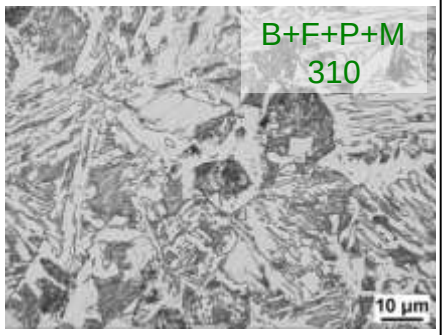
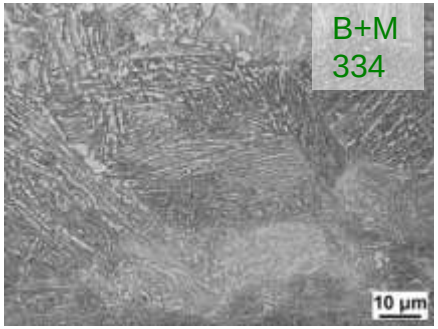
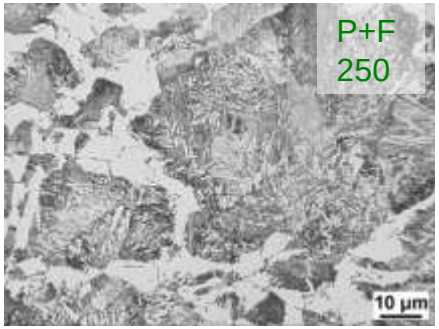




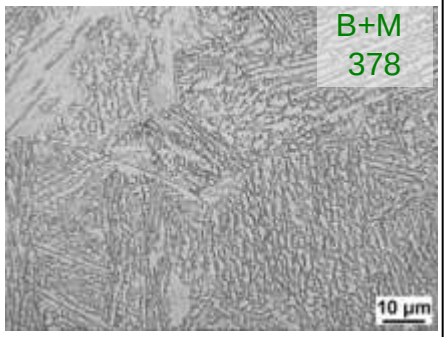
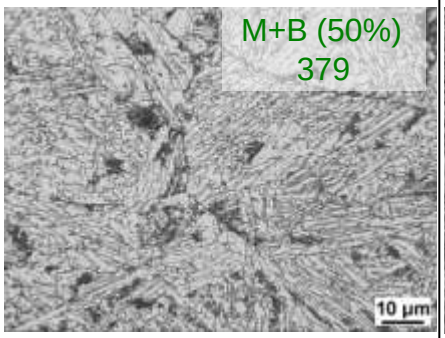
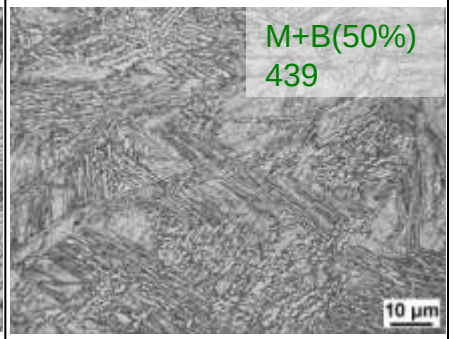
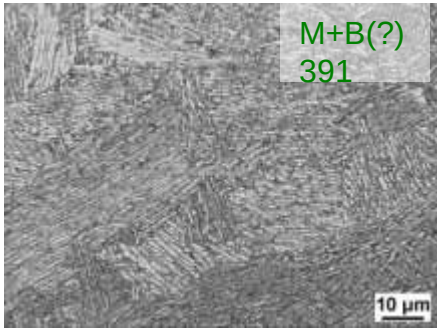
with deformation

WUMSI (Continuous cooling)

MP_B

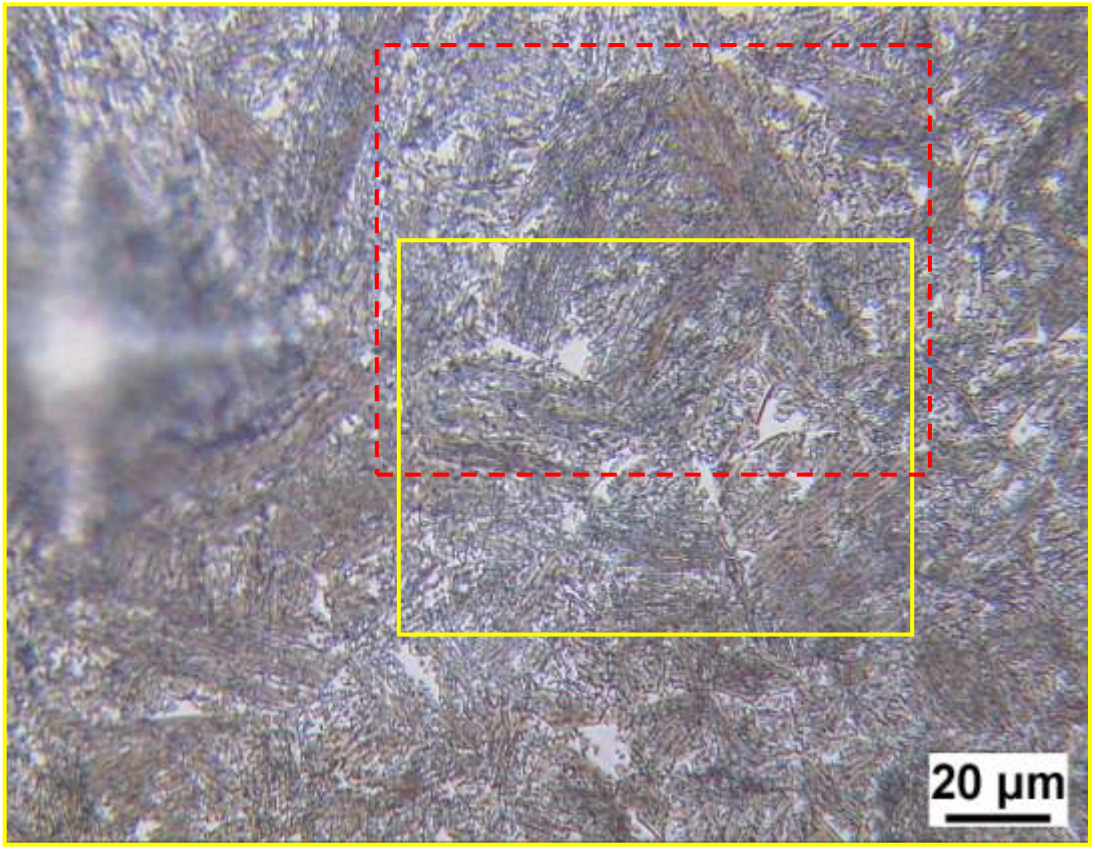
700°C without def.	600°C without def.	700°C with def.	600°C with def.
			

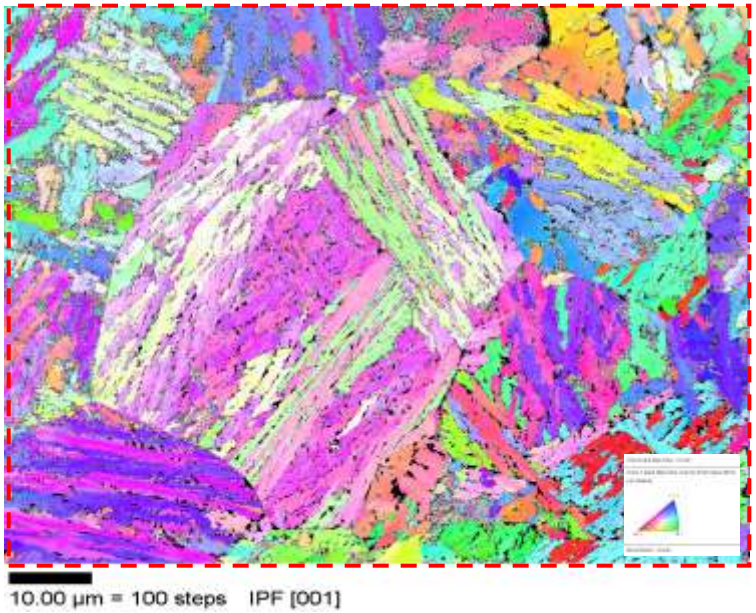
MP_CrMoB

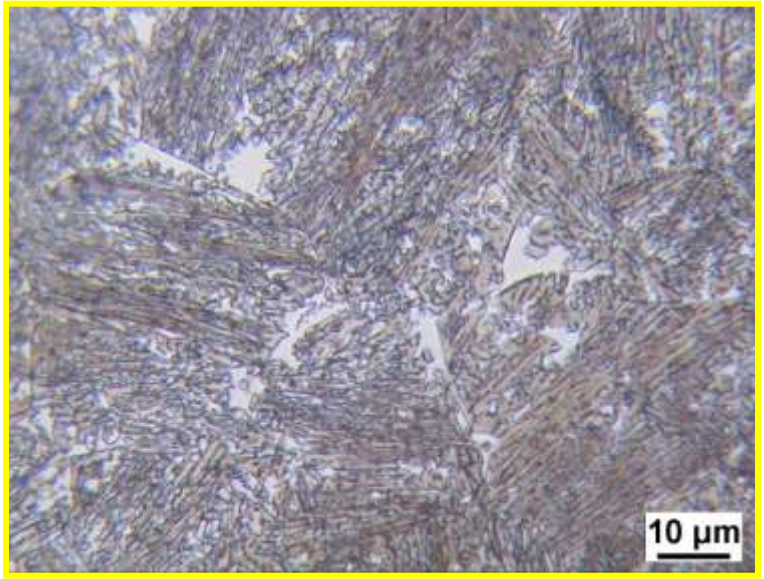
700°C without def.	600°C without def.	700°C with def.	600°C with def.
			

Content

WUMSI (LePera-etching, EBSD map)





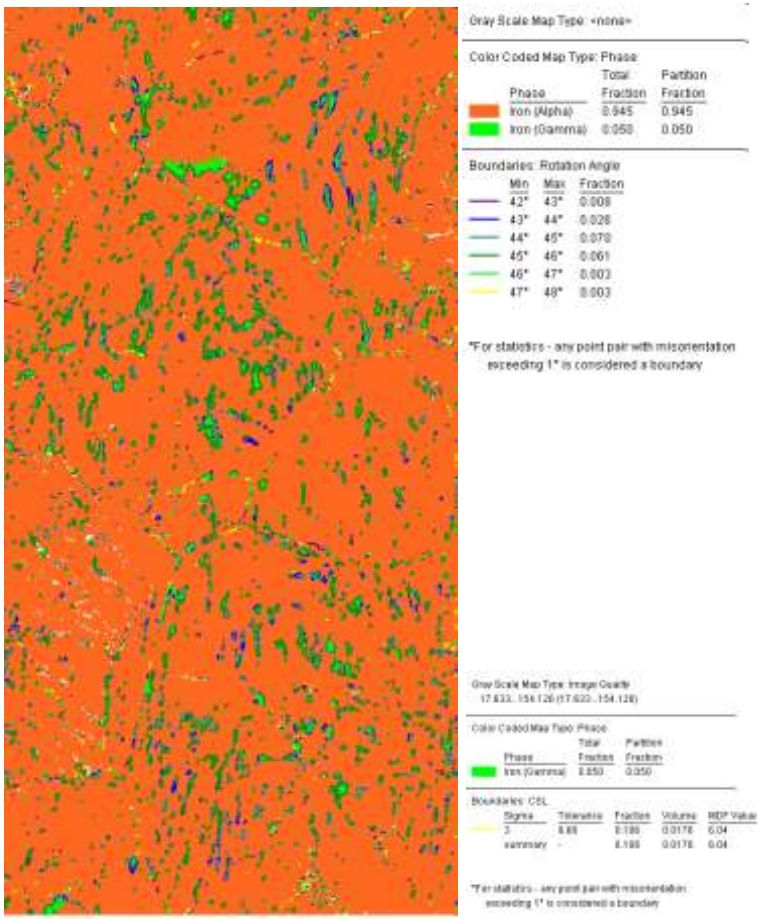


MP_Mo:

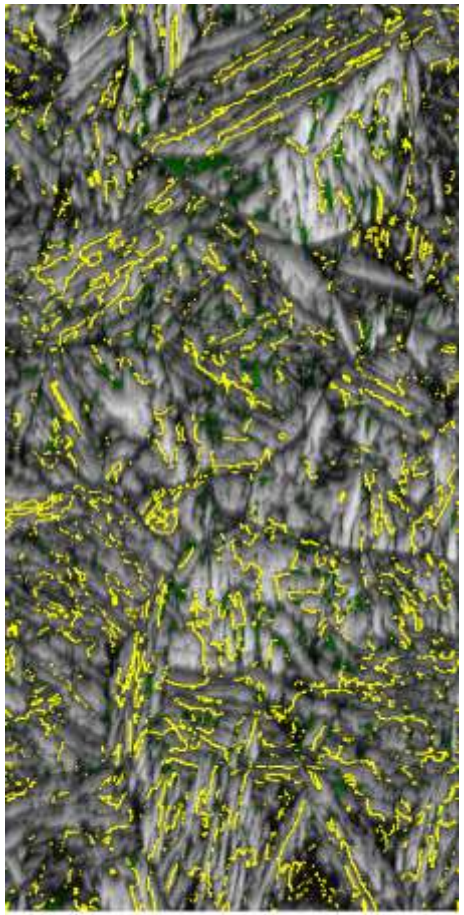
- without deformation
- Isothermal holding (1h@400°C)
- HV5: 501

Content

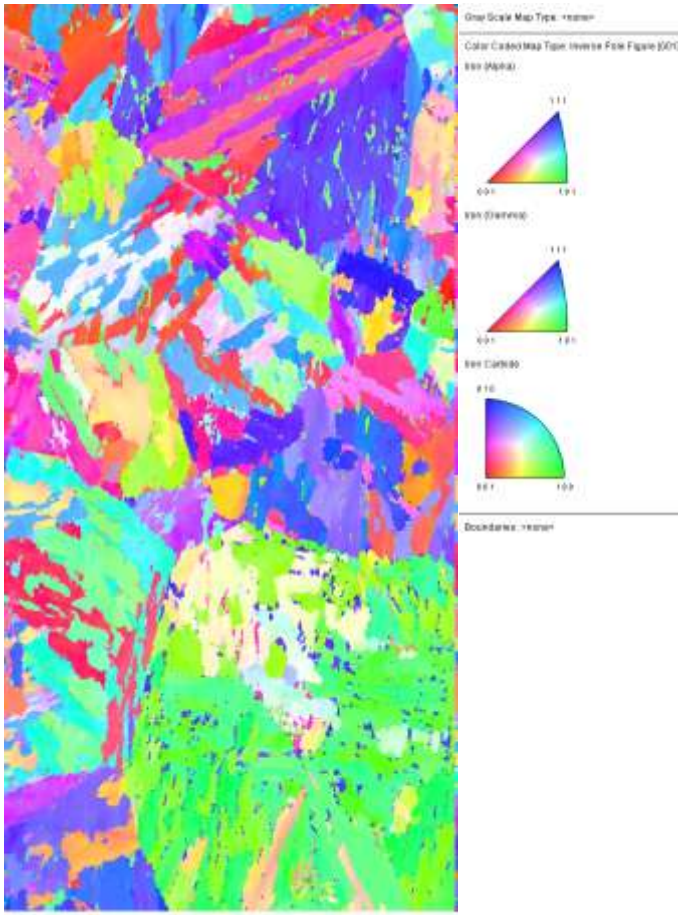
WUMSI (EBSD maps, Mo_iso_400_oU)



10.00 µm = 100 steps

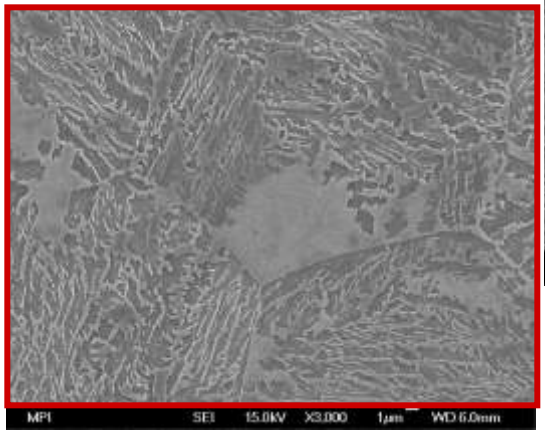


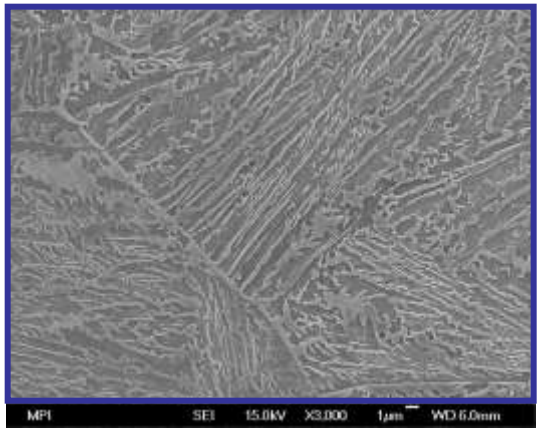
10.00 µm = 100 steps

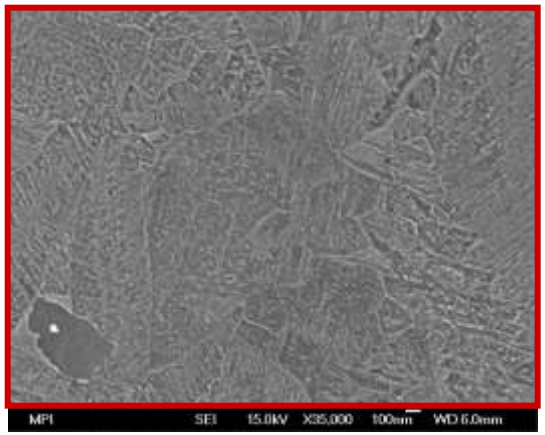


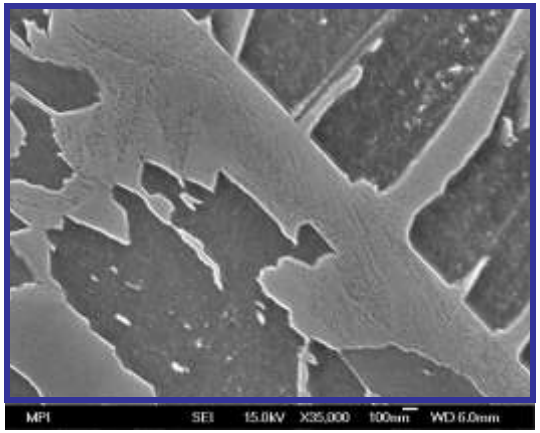
10.00 µm = 100 steps

WUMSI (SEM-graph, Mo_iso_400_oU)

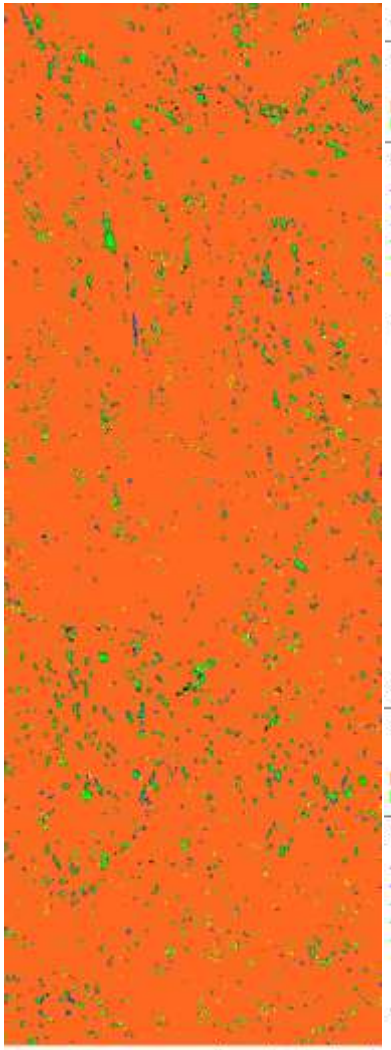








WUMSI (EBSD maps, Mo_iso_450_oU)



Gray Scale Map Type: <none>

Color Coded Map Type: Phase

Phase	Total Fraction	Partition Fraction
Iron (Alpha)	0.985	0.985
Iron (Gamma)	0.030	0.030

Boundaries: Rotation Angle

Min	Max	Fraction
42°	43°	0.004
43°	44°	0.007
44°	45°	0.010
45°	46°	0.009
46°	47°	0.004
47°	48°	0.003

*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

Gray Scale Map Type: <none>

Color Coded Map Type: Phase

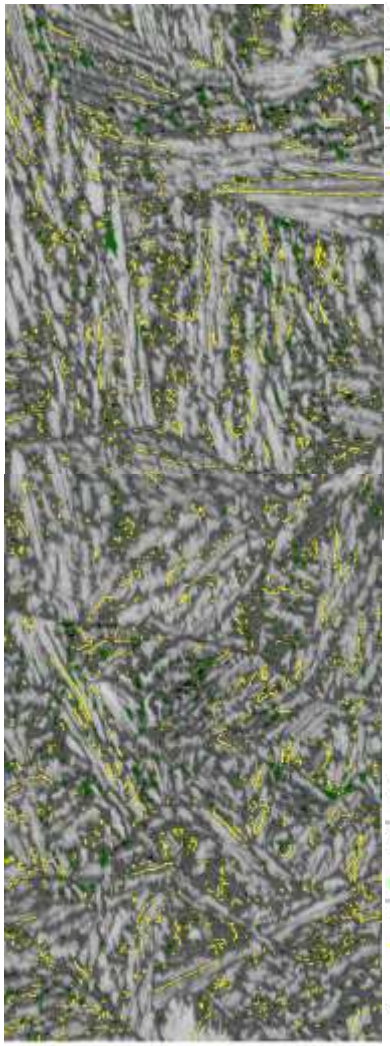
Phase	Total Fraction	Partition Fraction
Iron (Alpha)	0.968	0.968
Iron (Gamma)	0.030	0.030

Boundaries: Rotation Angle

Min	Max	Fraction
42°	43°	0.004
43°	44°	0.008
44°	45°	0.010
45°	46°	0.008
46°	47°	0.003
47°	48°	0.003

*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

10.00 µm = 100 steps Boundary levels: 42 Phase



Gray Scale Map Type: Image Quality
0...70.134 (0...70.134)

Color Coded Map Type: Phase

Phase	Total Fraction	Partition Fraction
Iron (Gamma)	0.030	0.030

Boundaries: CSL

Sigma	Tolerance	Fraction	Volume	MDF Value
3	8.66	0.024	0.0176	1.36
summary	-	0.024	0.0176	1.36

*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure (001)

Iron (Alpha)

Iron (Gamma)

Boundaries: <none>

Gray Scale Map Type: Image Quality
0...71.383 (0...71.383)

Color Coded Map Type: Phase

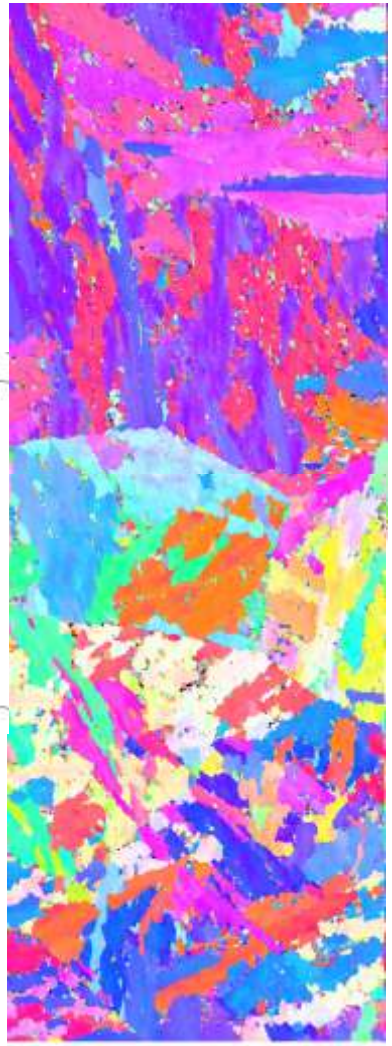
Phase	Total Fraction	Partition Fraction
Iron (Gamma)	0.030	0.030

Boundaries: CSL

Sigma	Tolerance	Fraction	Volume	MDF Value
3	8.66	0.023	0.0176	1.29
summary	-	0.023	0.0176	1.29

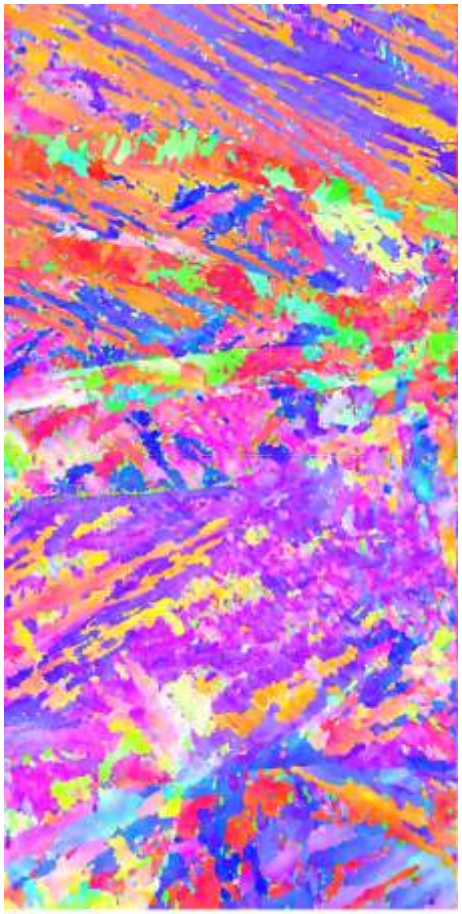
*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

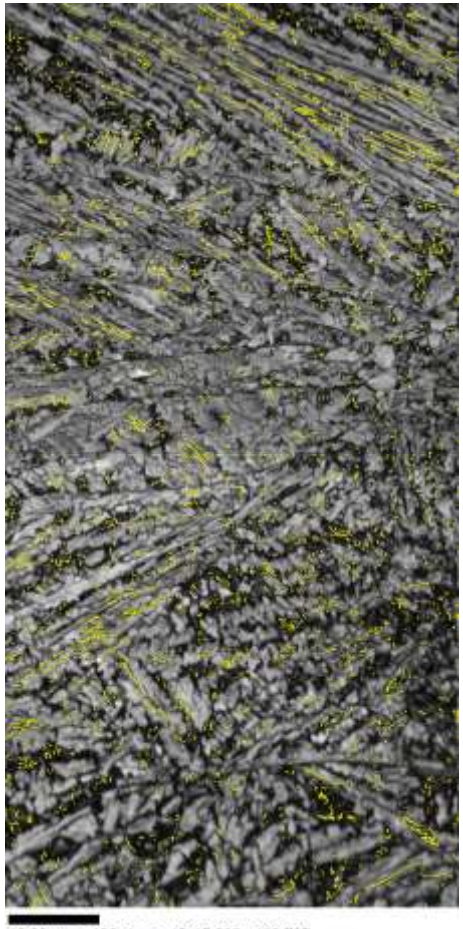
10.00 µm = 100 steps IQ 0...71.383, Phas

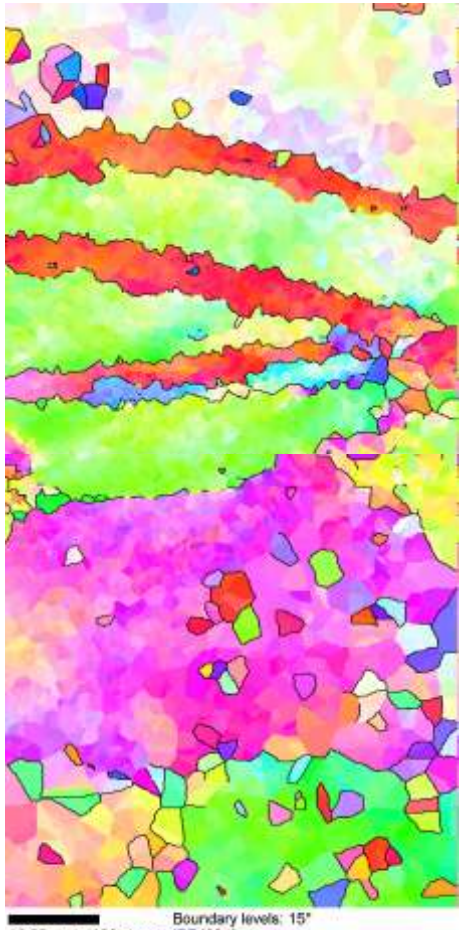


10.00 µm = 100 steps IPF [001]

WUMSI (EBSD maps, Mo_iso_400_mitU)







Gray Scale Map Type: <none>

Color Coded Map Type: Phase

Phase	Total Fraction	Partition Fraction
Iron (Alpha)	0.941	0.941
Iron (Gamma)	0.059	0.059

Boundaries: Rotation Angle

Min	Max	Fraction
42°	43°	0.010
43°	44°	0.026
44°	45°	0.047
45°	46°	0.036
46°	47°	0.002
47°	48°	0.002

*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

Gray Scale Map Type: Image Quality

Color Coded Map Type: <none>

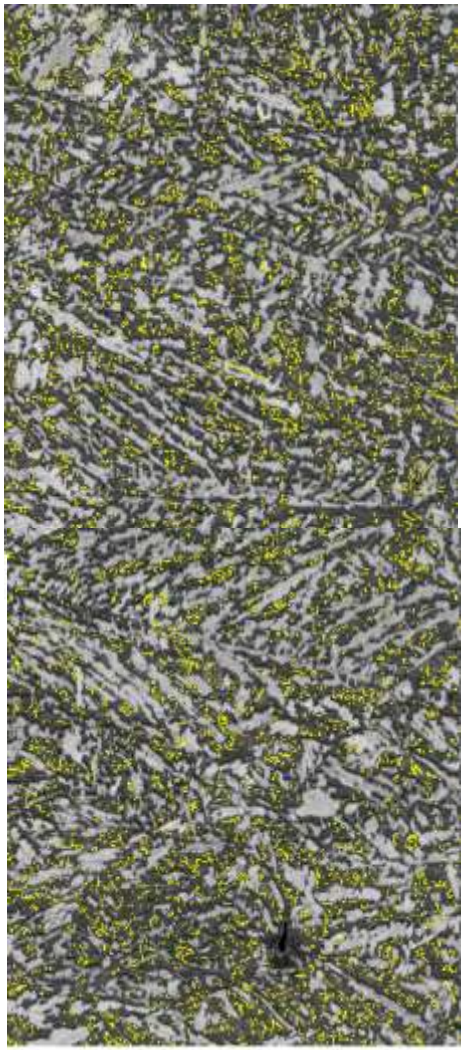
Boundaries: CSL

Sigma	Tolerance	Fraction	Volume	MDF Value
3	0.66	0.040	0.0176	2.36
summary	-	0.040	0.0176	2.36

*For statistics - any point pair with misorientation exceeding 1° is considered a boundary

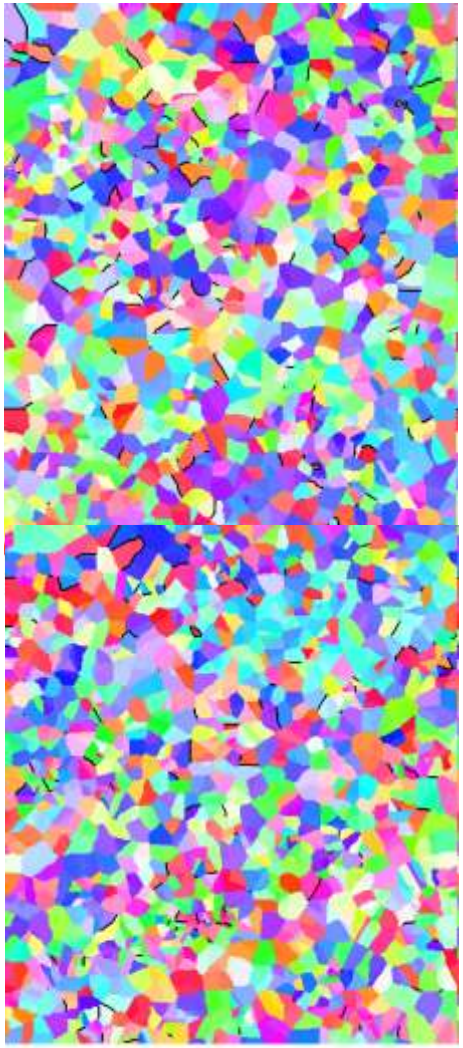
WUMSI (EBSD maps, Mo_iso_450_mitU)

10.00 µm = 100 steps Boundary levels: 42° 43° 44° 45° Phase



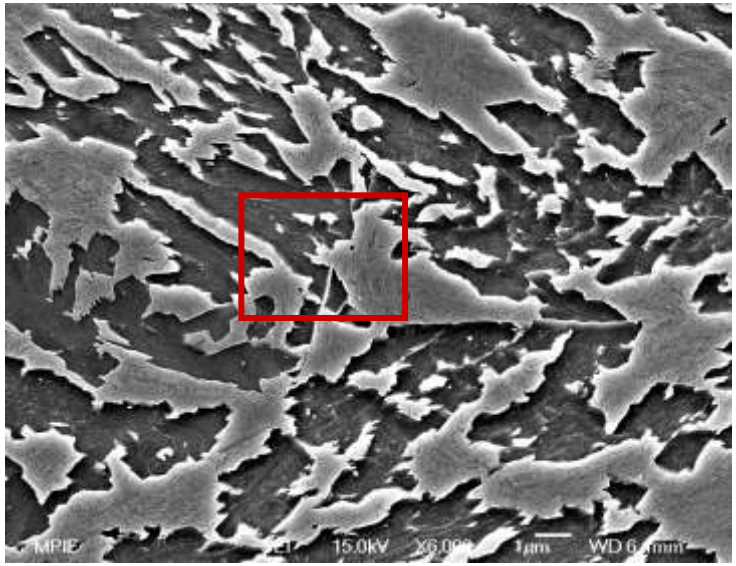
10.00 µm = 100 steps IQ 0...85.26, Phase

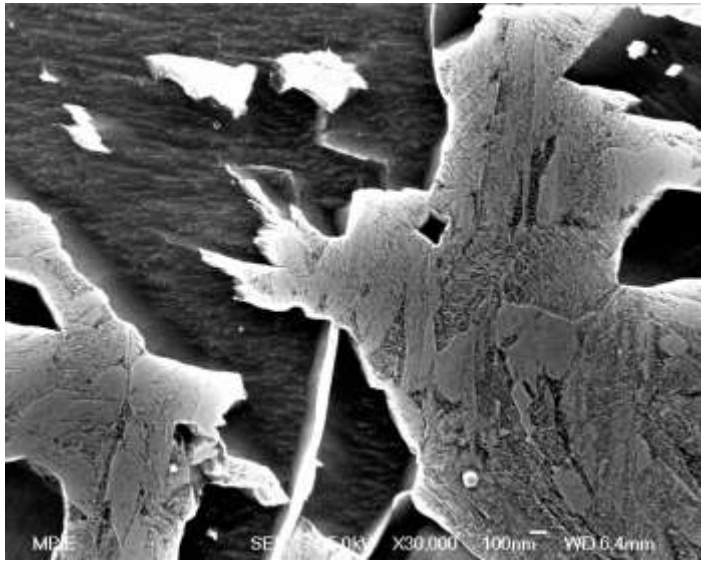
10.00 µm = 100 steps IPF [001]



10.00 µm = 100 steps IPF [001]

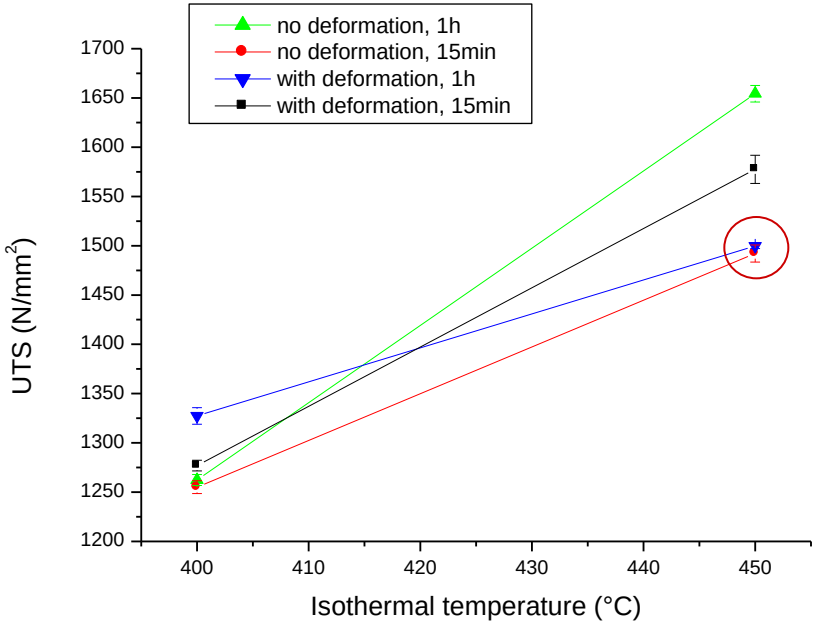
WUMSI (SEM-graph, Mo_iso_450_mitU)

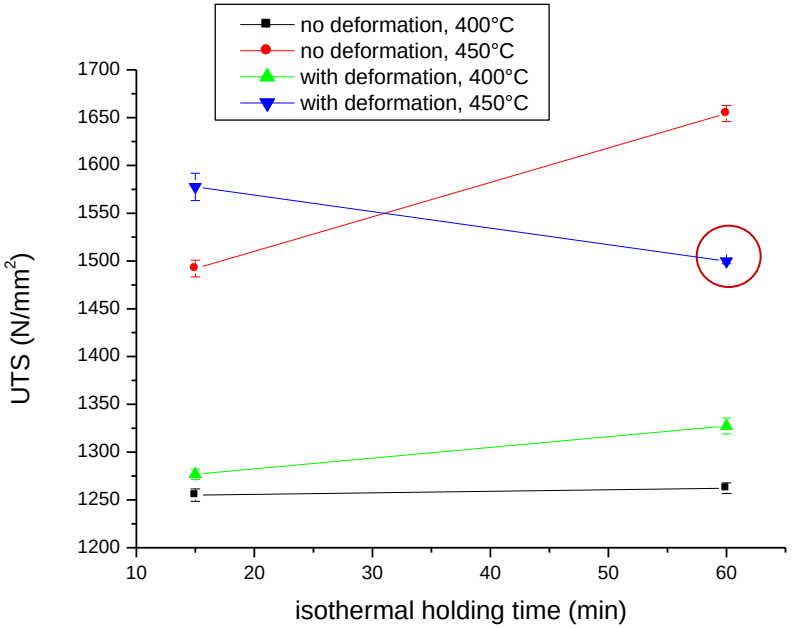


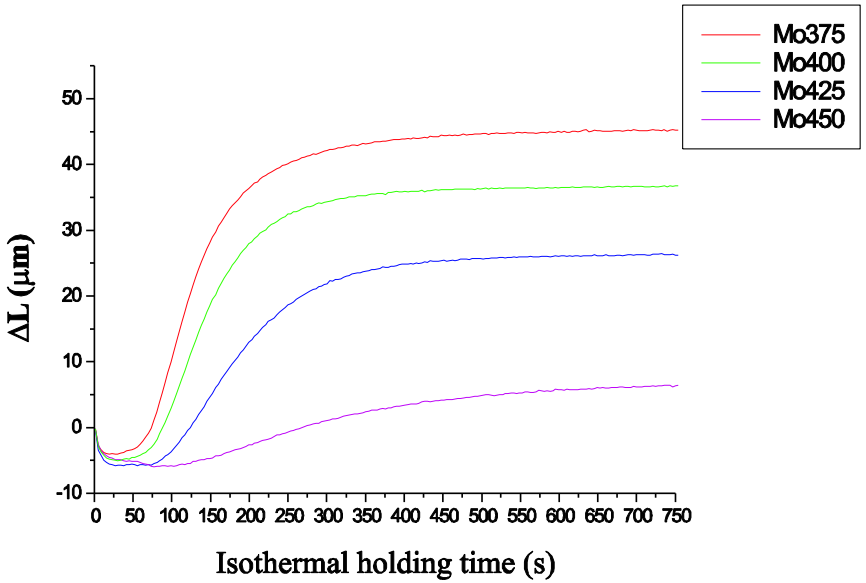


Content

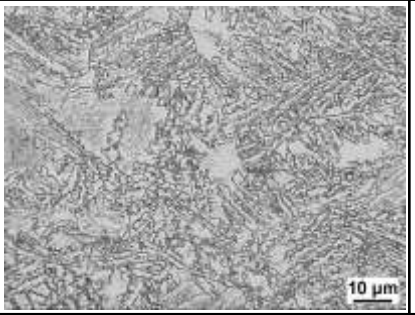
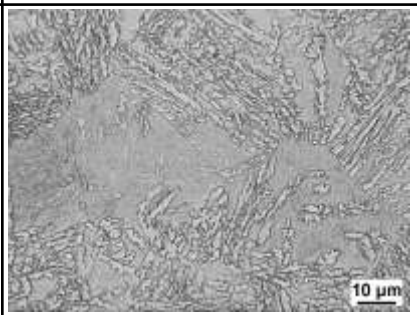
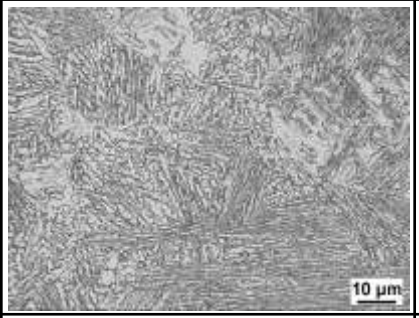
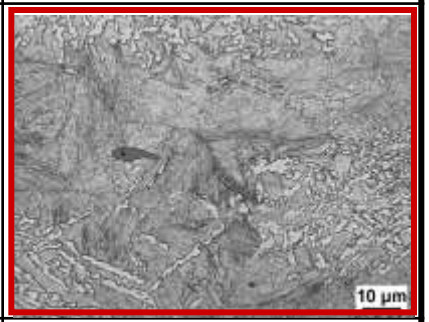
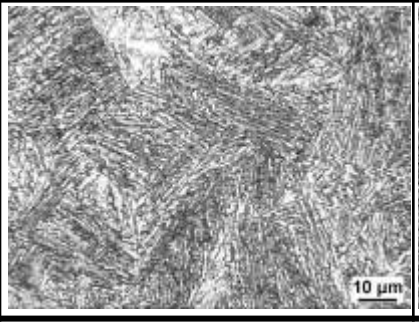
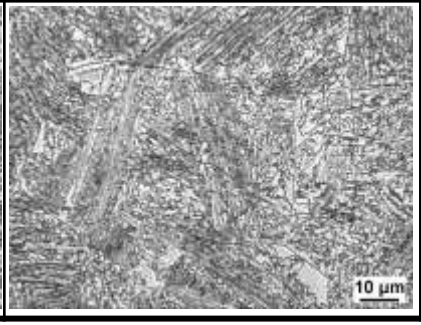
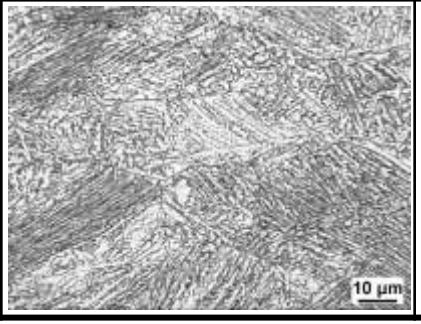
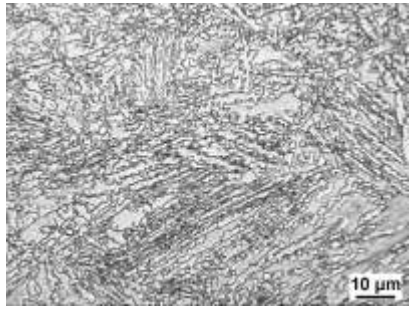
Tensile Tests for MP_Mo steel





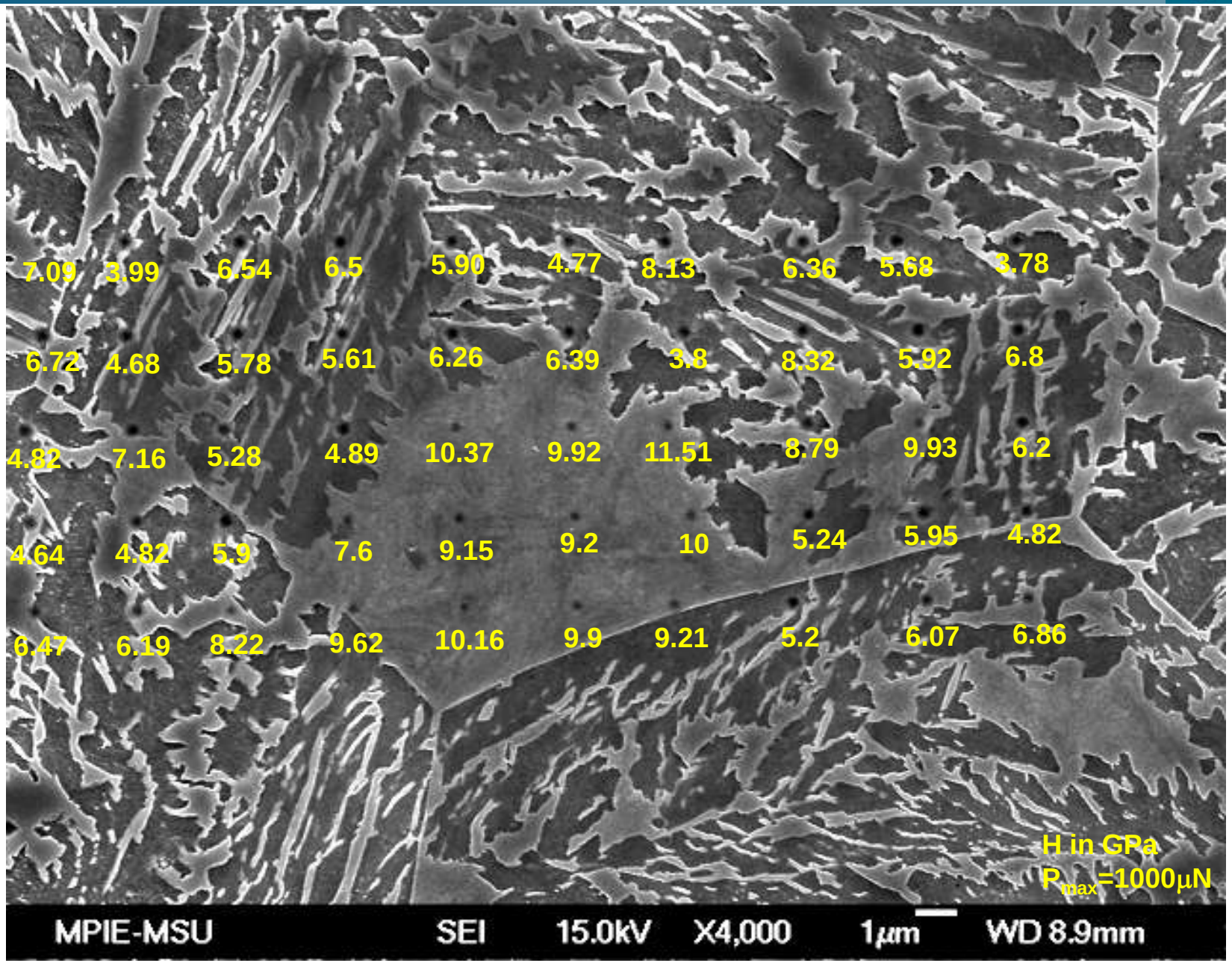


Transformation Behavior of MP_Mo

	No deformation		With deformation	
	T_{iso}=400°C	T_{iso}=450°C	T_{iso}=400°C	T_{iso}=450°C
t_{iso}=60min				
t_{iso}=15min				

Content

Nano-Indentation, (Mo_iso_400_oU)



Conclusion

• Using EBSD microstructural characteristics can be revealed. This method can be supported by LePera etching or nano-indentation.

• Additional alloying elements have a strong influence on the bainitic transformation and after all trials the most promising steels can be fixed:

- for isothermal treatment: MP_B and MP_Mo
- for continuous cooling treatment: MP_B and MP_CrMoB

• The influence of deformation on the bainitic transformation is less than that of the additional alloying elements and the variation of the process parameters (e.g. isothermal holding temperature)

Future work

- **Tensile tests** for all steels with promising microstructures

- **Charpy-V-notch tests** to investigate the toughness properties

- **Nanoindentation** tests not only to identify the single constituents but also to determine the their mechanical properties and compare these results with the mechanical properties of the whole sample

- **X-ray measurement** to define volume fraction of retained austenite and its C content → stability of retained austenite