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steels for car-body

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# **ADVANCED HIGH-STRENGTH STEELS FOR CAR-BODY MANUFACTURING**

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# Overview

- Introduction: steel sheets for car bodies
- TWIP steel characterization
- Q&P steel development and characterization
- Welding and fatigue tests
- Conclusions

# Steel sheets for car bodies (I)

## *Desired properties*

*Higher strength  
→ lower weight →*

*Lower fuel consumption  
Less pollution (Euro 4 – 5 ...)  
Increased load (commercial vehicles)  
Lower cost*

*Plastic energy absorption → car-crash safety*

*Fatigue endurance → ordinary car service*

*Ductility, weldability → production processes*

# Steel sheets for car bodies (II)

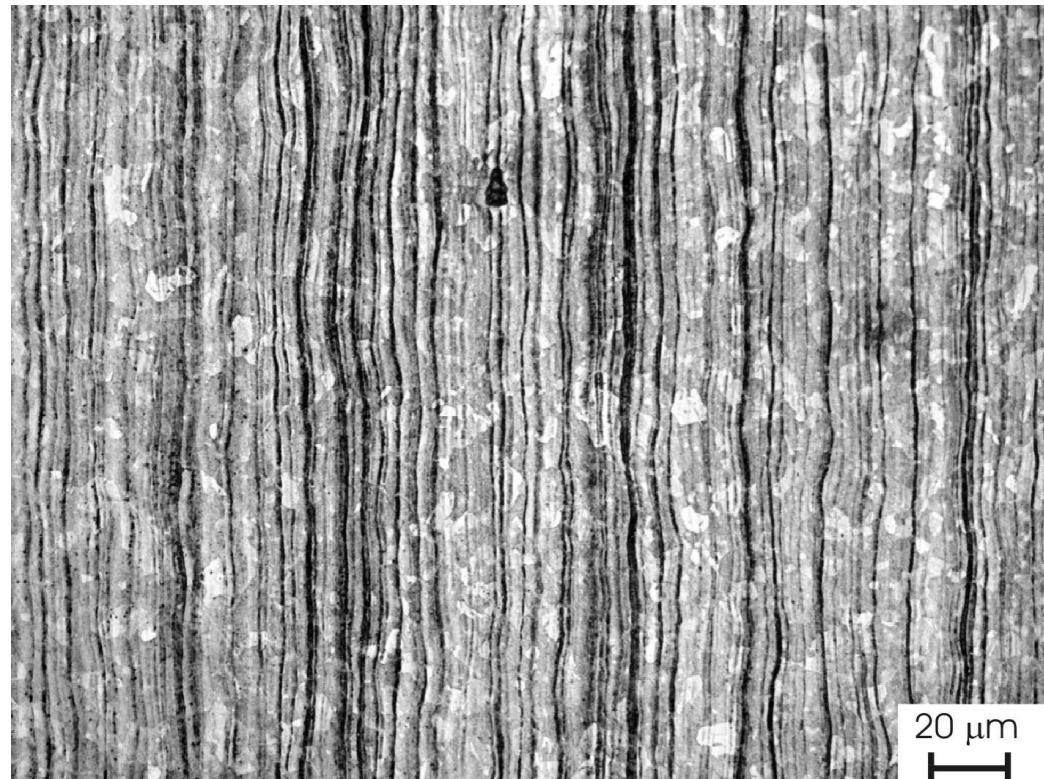
## *Most common overall production cycle*

- High-strength weldable steel sheets are made by:
  - continuous casting
  - hot rolling
  - cold rolling
  - continuous final heat treatment
  - protective coating (Zn)
- Sheets are **cold formed** to produce car body parts
- Car bodies are assembled by **welding**, most commonly by **resistance spot welding**

# TWIP Steel - Composition & microstructure

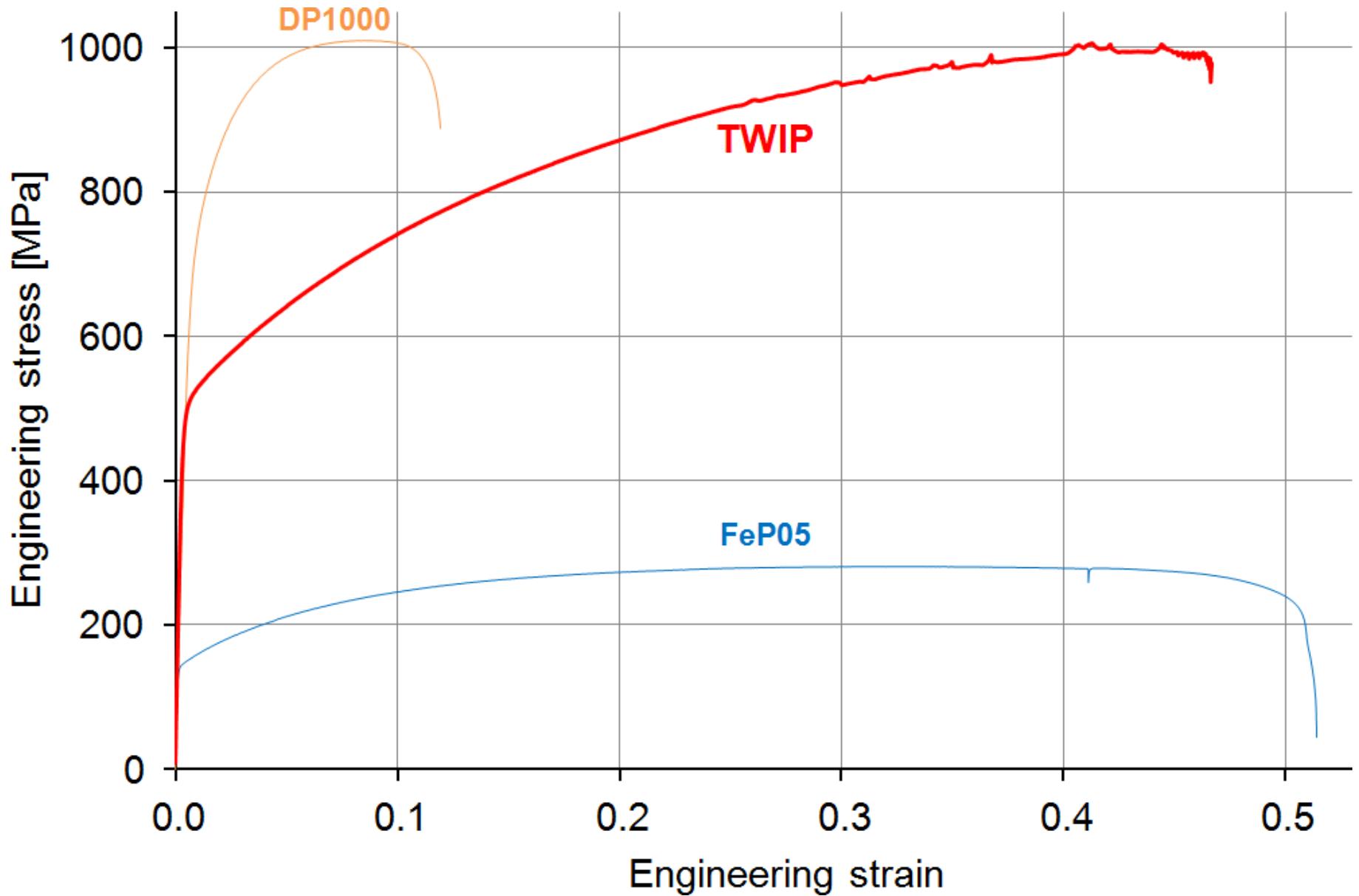
- TWIP: TWinning Induced Plasticity
- Industrial sheets (used for car-body parts, not yet commonplace)
- Fully austenitic (OM and XRD), 3  $\mu\text{m}$  grain size, banding (OM)

Wt. %	
C	0.65
Mn	18.3
Al	1.5
Ni	0.41
Cr	0.02
Si	0.05
Cu	0.05
V	0.04
P	0.02
S	0.01

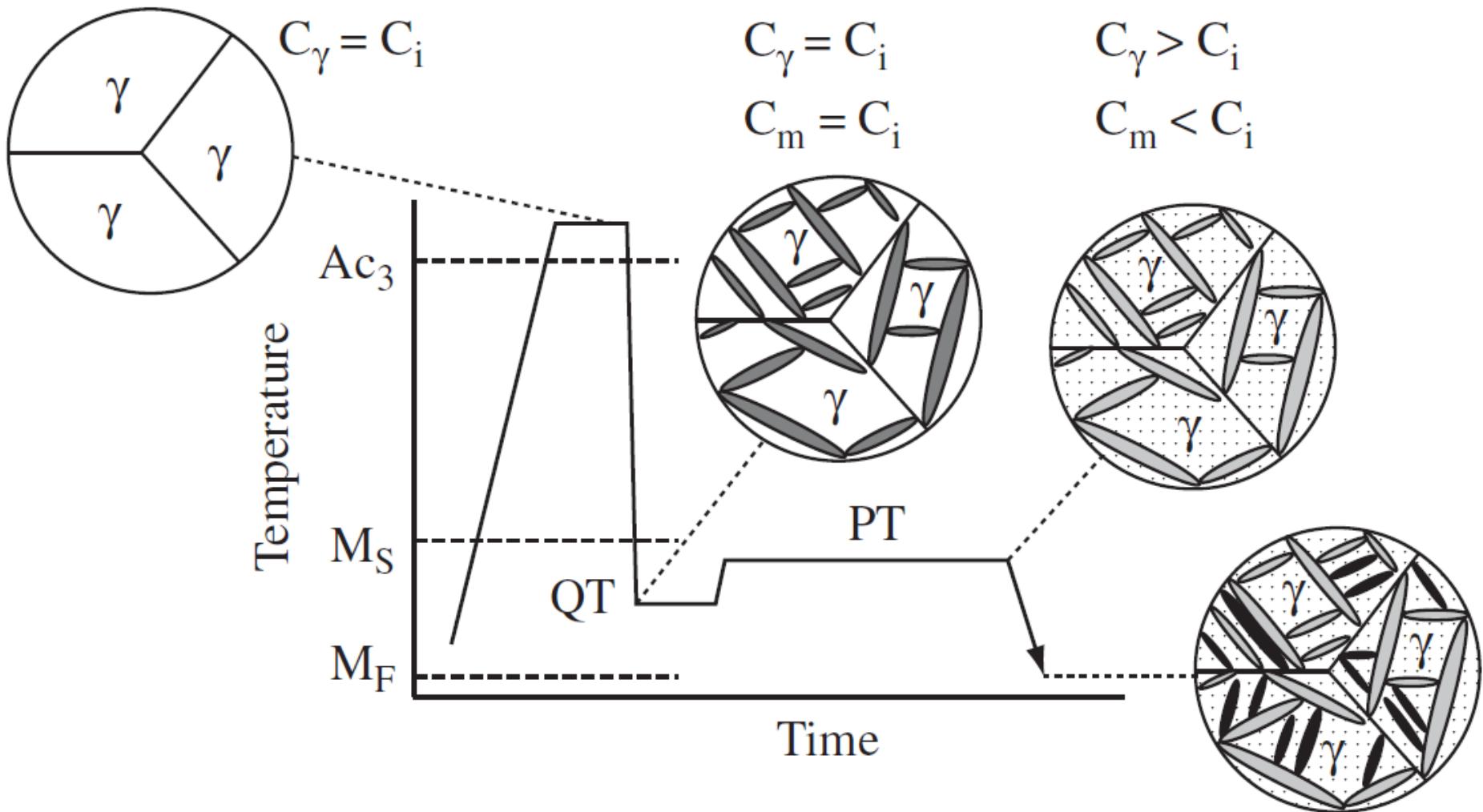


OM, etchant: 1ml HNO<sub>3</sub>, 2 ml HCl, 3 ml glycerol

# TWIP Steel - Tensile testing



# Q&P steel - The Quenching & Partitioning concept



# Q&P steel – Experimental alloys & heat treatments

- ✓ Ingot casting with 3 different compositions:

	C	Mn	Si	Mo	Al	P	S	B	A <sub>c1</sub>	A <sub>c3</sub>
“Si”	0.22	1.6	1.6	0.003	0.05	0.016	0.014	0.0006	725	915
“Si-Mo”	0.21	1.8	1.6	0.17	0.006	0.016	0.016	0.0007	730	911
“Al”	0.23	1.6	0.4	0	1.1	0.014	0.024	0.0004		

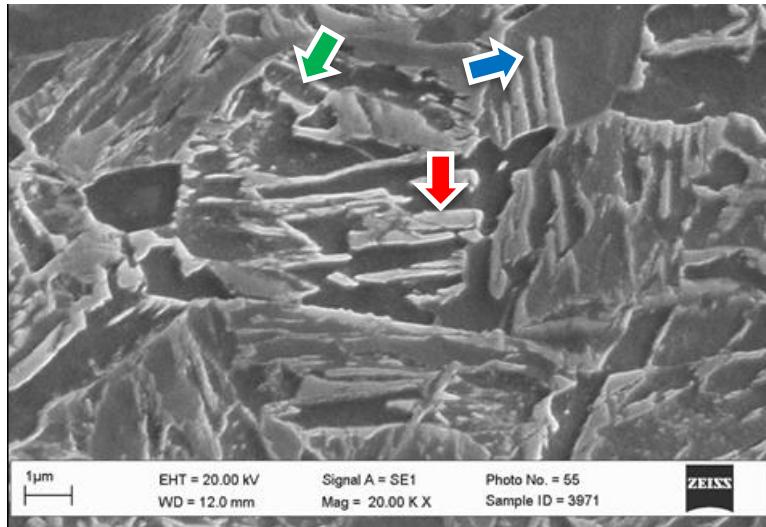
- ✓ Hot and cold rolling of 260 x 50 x 1 mm strips
- ✓ Q&P heat treatment with 9 different schedules (\*):

	1	2	3	4	5	6	7	8	9
Austenitizing [°C]	820	850	870	850	850	900	900	950	950
[s]	134	134	134	180	180	180	180	60	60
Quenching [°C]	250	250	250	220	220	240	240	220	190
[s]	83	83	83	20	20	10	10	20	20
Partitioning [°C]	460	460	460	350	450	350	450	350	350
[s]	12	12	12	60	60	10	10	60	60

(\*) induction heating and air cooling of a 50 x 40 mm mid-strip area.

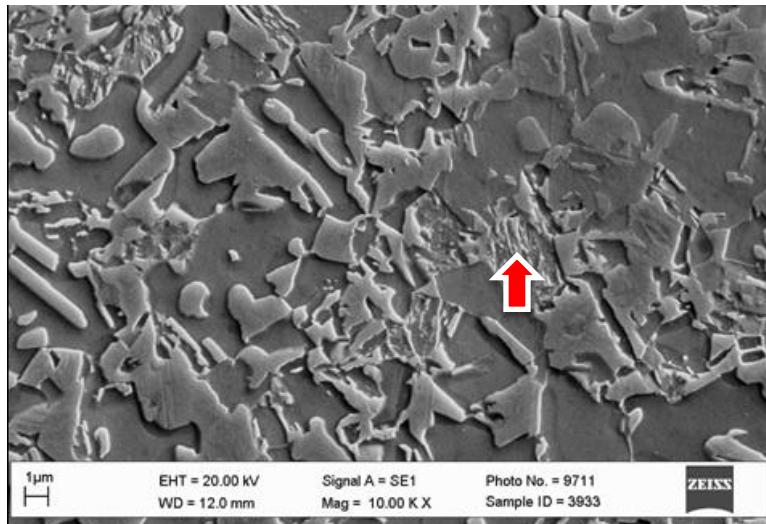
# Q&P steel - Microstructural constituents

Si-Mo-3



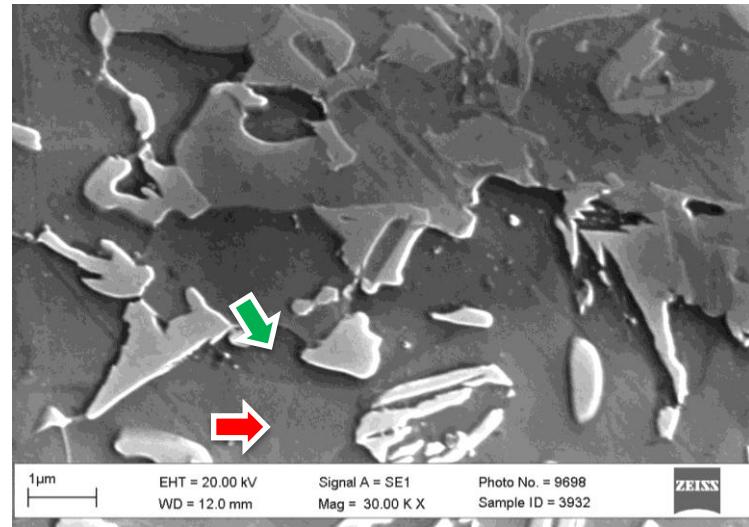
Lath martensite, bainite, austenite

Si-Mo-1



Tempered martensite

Si-1



Intercritical and epitaxial Ferrite

Si-Mo-1

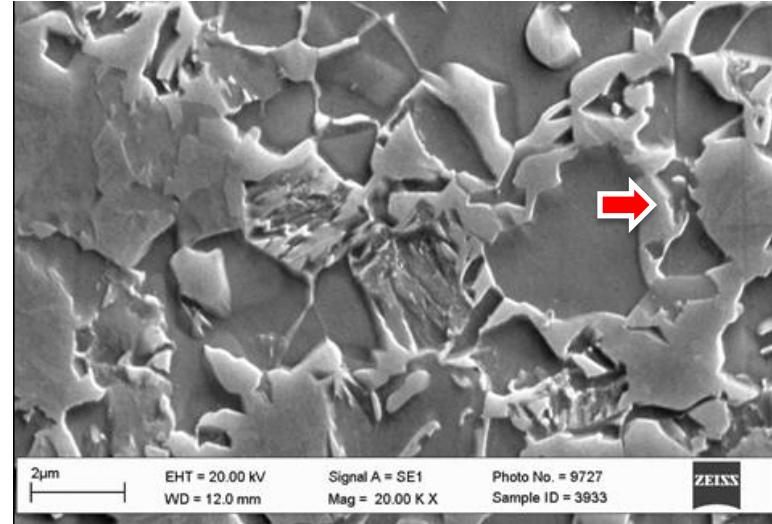


Plate Martensite

Sheet plane, etching: 0.5% Nital + 2% Picral

# Q&P steel - Microstructural constituents

Si-3

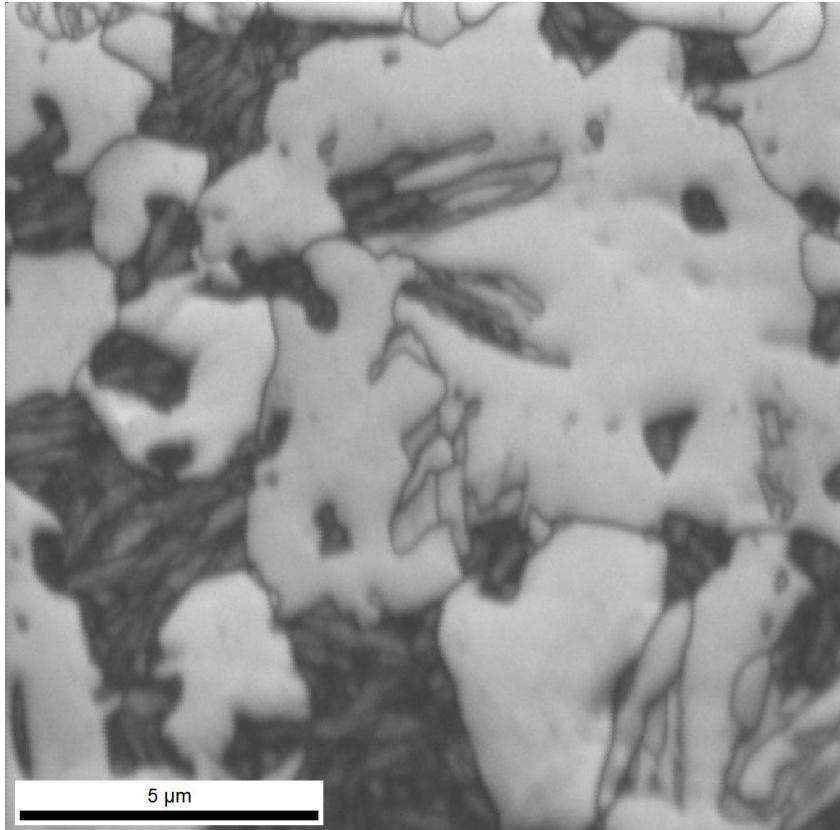


Image quality map

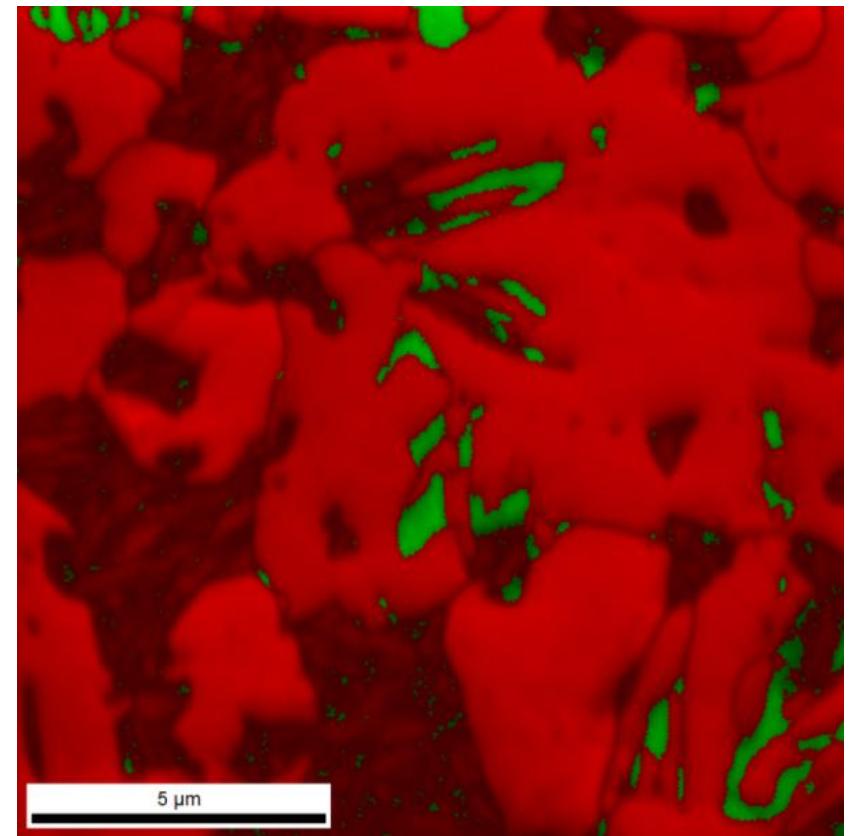
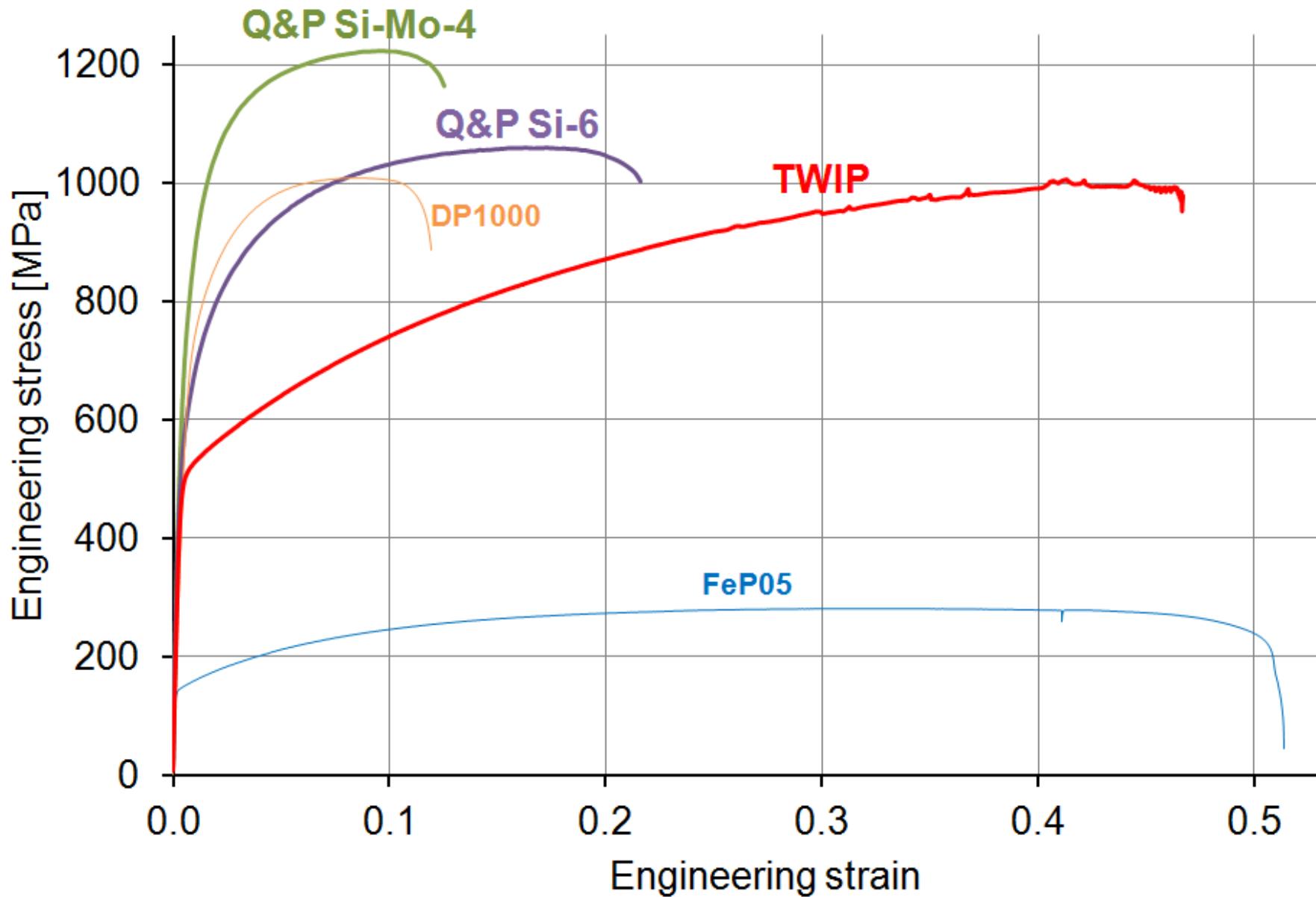


Image quality map (brightness)  
+ **BCC** / **FCC** phase map (color).

# Q&P steel - Tensile tests results & steels selection

Results [HV1, MPa, %]	Q&P schedule								
	1	4	5	2	3	6	7	8	9
<b>"Si"</b>	$\gamma$	7.4	3.5	8.1	6.4	6.0	<2	<2	<2
	HV1	272	276	244	270	261	233	256	376
	UTS	947	1067	938	949	1021	1071	1163	1153
	YS	362	404	372	373	584	636	503	778
	EI.	12.0	19.5	22.0	17.9	19.3	19.8	15.1	10.8
<b>"Si-Mo"</b>	$\gamma$	2.7	3.5	7.2	6.4	5.7	n. a.	<2	<2
	HV1	347	373	337	358	418	380	445	444
	UTS	1159	1228	1122	1125	1294	1266	1400	1318
	YS	513	685	797	743	1178	1126	1041	1086
	EI.	9.2	13.3	17.1	17.5	8.9	7.3	7.1	6.2
<b>"Al"</b>	$\gamma$	9.6	6.2	<2	7	4.5	5.1	n. a.	
	HV1	191	193	192	196	191	193	n. a.	
	UTS	765	832	712	700	734	746	831	
	YS	351	307	409	400	377	327	336	
	EI.	30.0	23.6	32.7	19.0	32.5	28.6	23.7	

# Q&P steels - tensile curves



# Welding tests - processes & tensile samples

## ***EBW – Electron Beam Welding***

Simulated welding lines (s-EBW) - Actual homologous butt welding

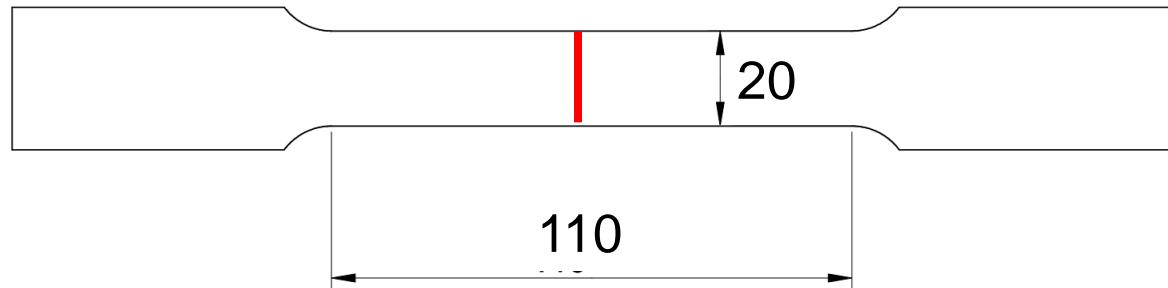
Speed: 0.8 m/min (Q&P) or 0.6 m/min (TWIP) - Current: 80 A - Argon

## ***LW - Laser Welding***

Simulated welding lines (s-LW)

Laser: NdYAG - Speed: 2.2 - 2.7 m/min - Power: 2.4 - 2.8 kW

*The tensile samples were cut from welded sheets, normal to the welding line.*

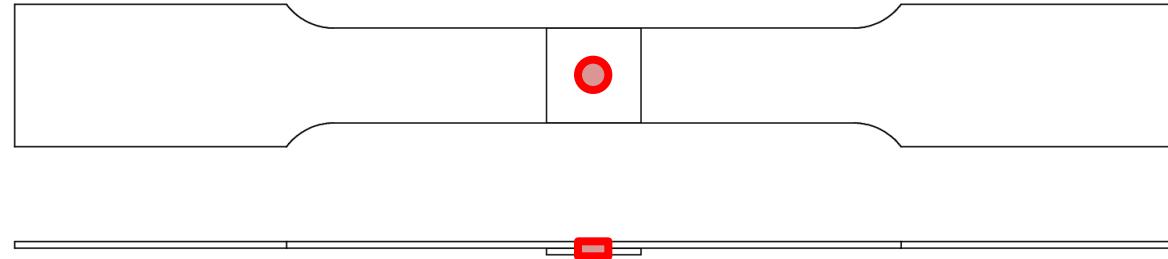


## ***RSW - Resistance Spot Welding***

Welding of homologous sheet specimens

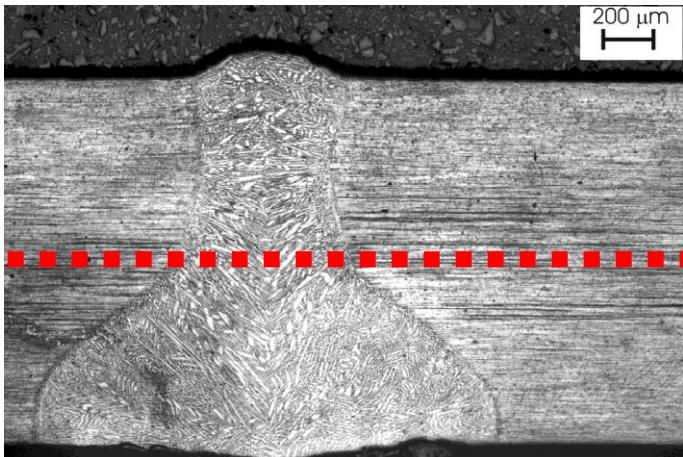
Spot radius: 3 mm - Force: 3.5 kN - Time: 260 ms - Current: 7 kA

*One small sheet square was welded at mid-length of each tensile sample*

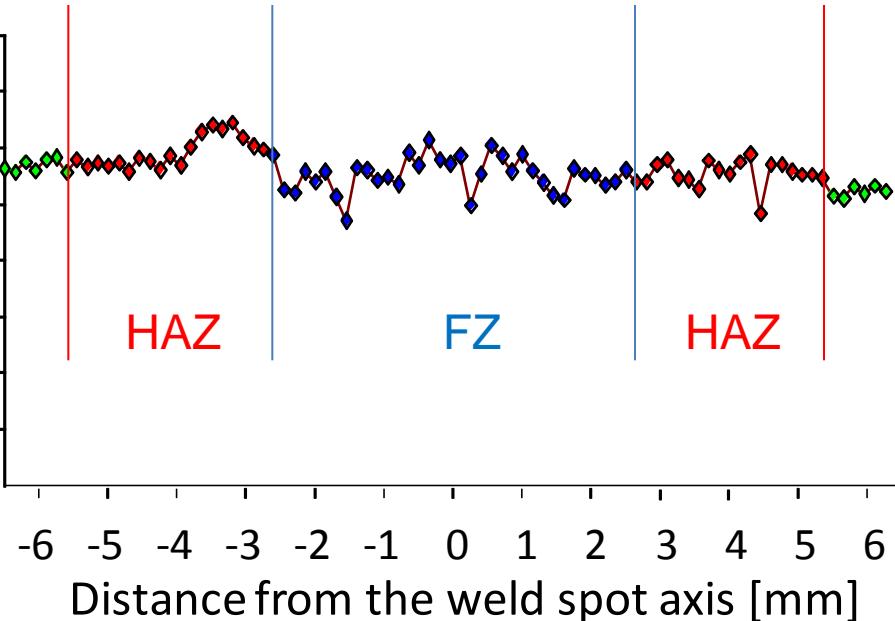
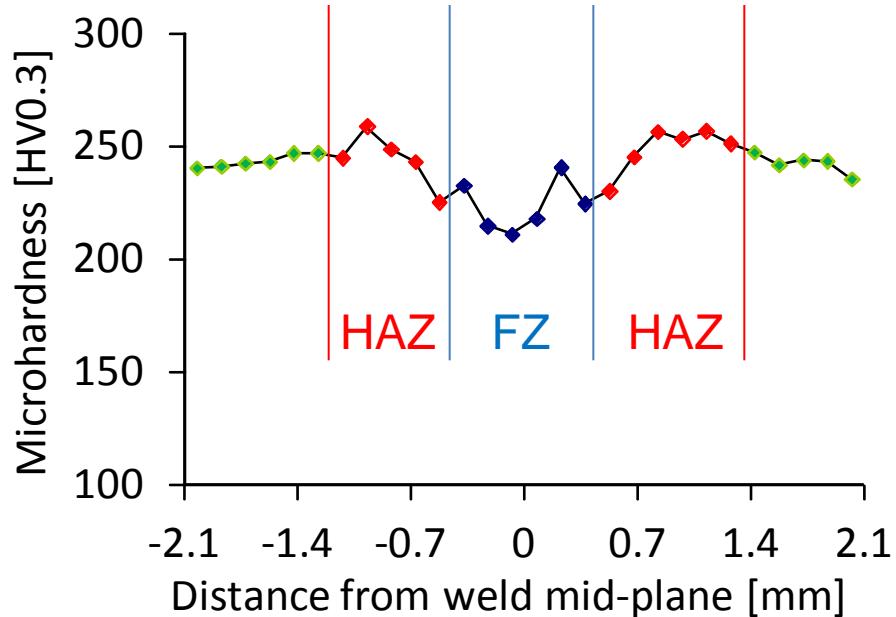
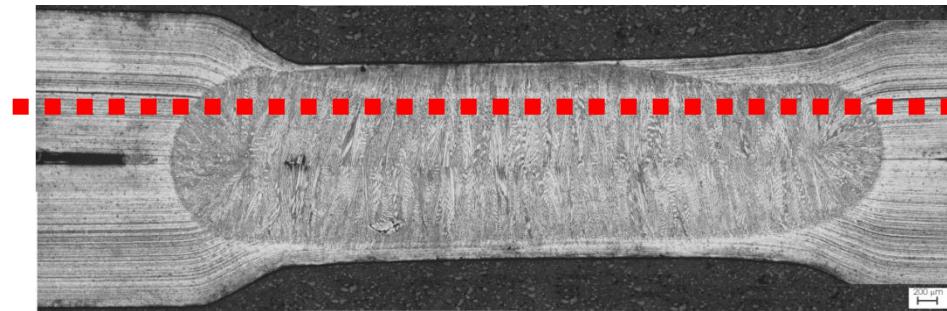


# Welding tests – microstructure and hardness

s-LW

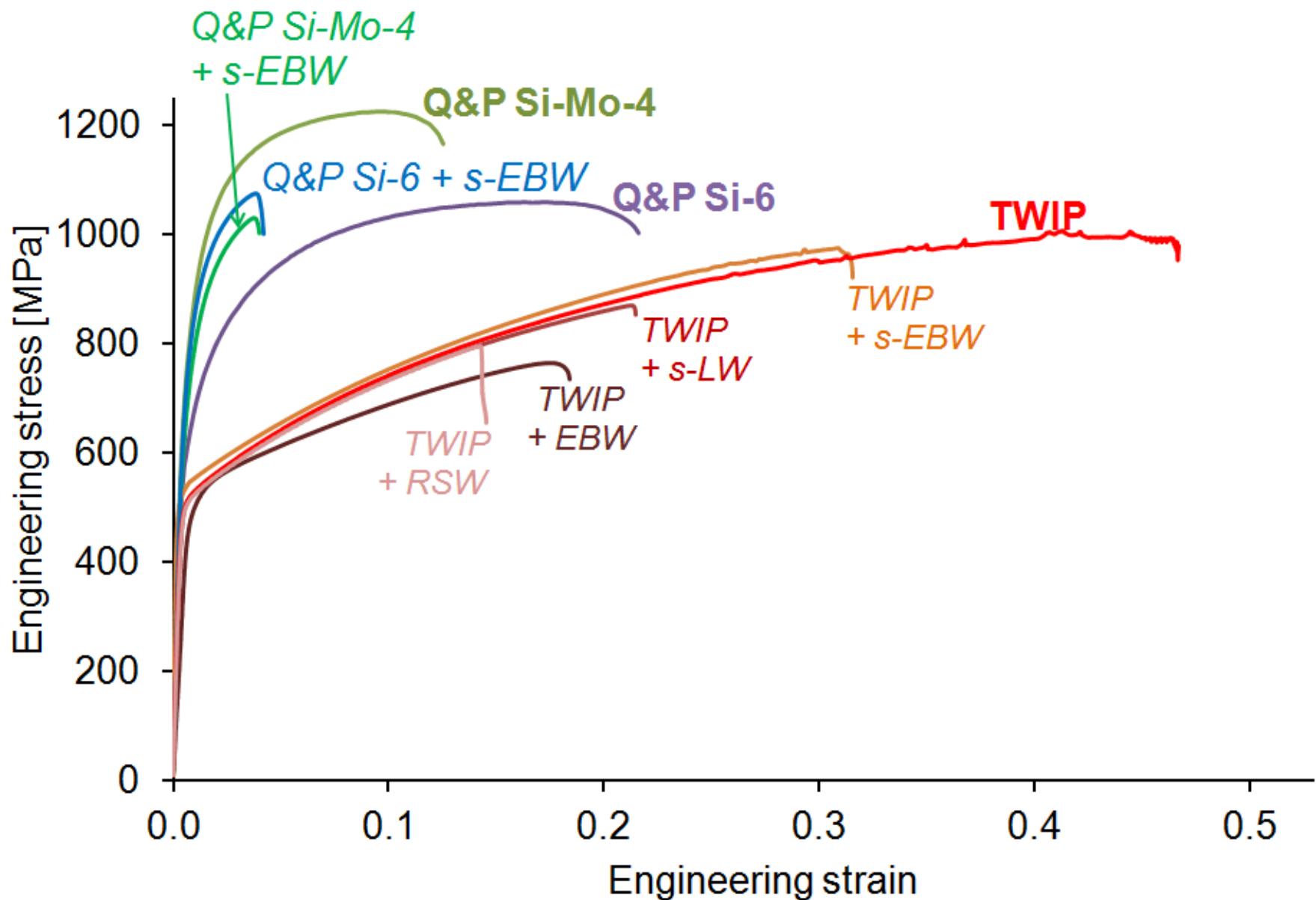


RSW



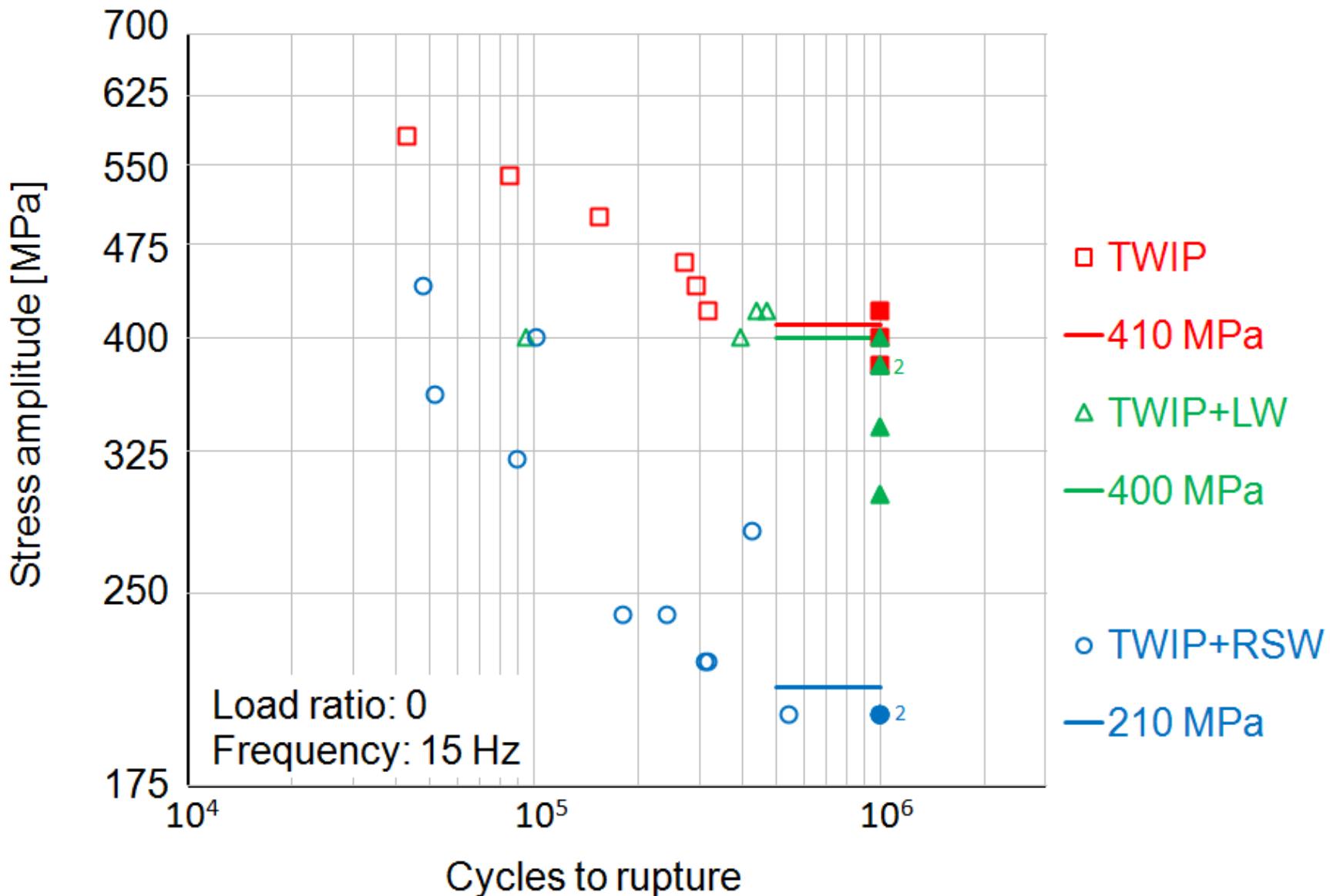
Etching: 10 ml HNO<sub>3</sub>, 20 ml HCl, 30 ml glycerin

# Welding tests – tensile curves



# Fatigue tests – 1 million cycles fatigue strength

## *Staircase method*



# Conclusions

- The examined, industrial, high-Mn **TWIP steel** exhibit a fully sostenitic structure, **1000 MPa UTS and 45% Elongation**
- 25 experimental **Quenching and Partitioning (Q&P)** steels were fabricated by combining 3 compositions and 9 heat treatment schedules
- On the basis of the ensuing tensile properties, the following Q&P steels were chosen (**composition - heat treatment - UTS, Elongation**):  
**0.2C, 1.6Mn, 1.6Si - 900°C 180s / 240°C 10s / 350°C 10s - 1070Mpa, 20%**  
**0.2C, 1.8Mn, 1.6Si, 0.2Mo - 850°C 180s / 220°C 20s / 350°C 60s - 1230MPa, 13%**
- The welding, tensile and fatigue tests on the TWIP and Q&P steels reveal that:
  - Welded samples exhibit similar tensile curves, but premature failures
  - Resistance spot welded tensile samples yield the worse results
  - The TWIP steel 1 million cycles fatigue strength is not diminished by laser welding, but is halved after resistance spot welding

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## **Thank you for your attention!**

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