[Other] Advanced high-strength steels for car-body manufacturing

ADVANCED HIGH-STRENGTH STEELS FOR CAR-BODY MANUFACTURING

D. Firrao, G. Scavino, P. Matteis,
Politecnico di Torino, Torino, Italy;

M. De Sanctis, R. Valentini, G. F. Lovicu, A. Di Matteo,
Università di Pisa, Pisa, Italy;

M R. Pinasco, M.G. Ienco, E. Pastore, O. Holovenko,
Università di Genova, Genova, Italy;

G. Silva, B. Rivolta, R. Gerosa,
Politecnico di Milano, Lecco, Italy.

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)

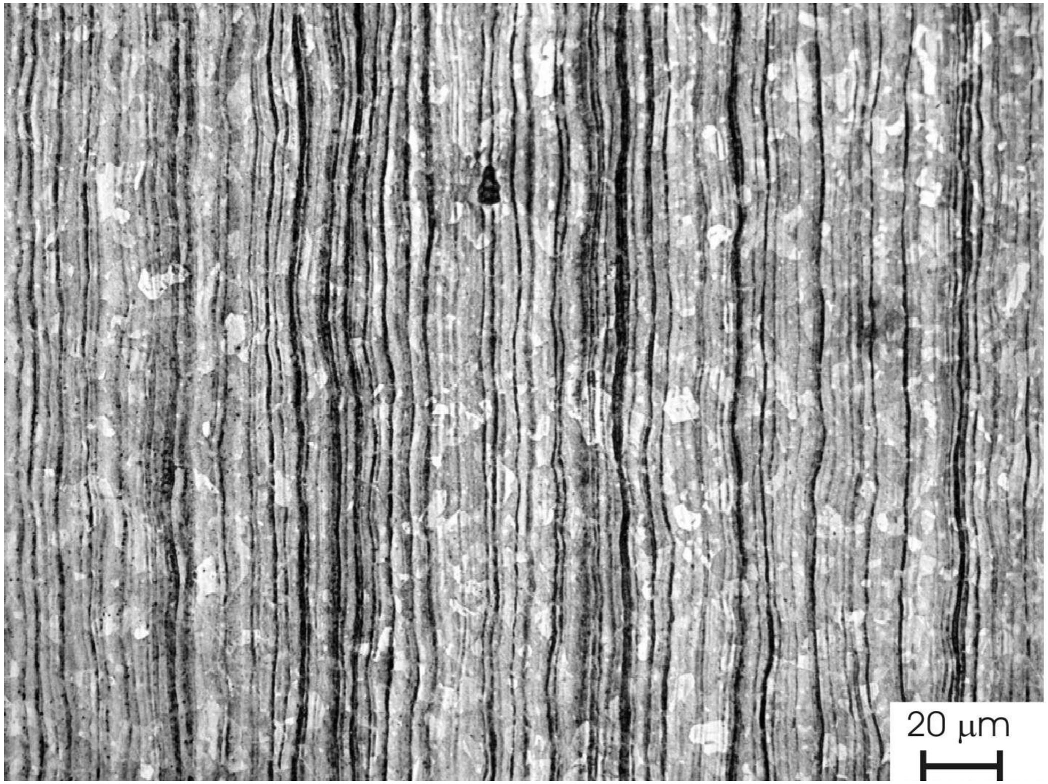
Most common overall production cycle

- 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

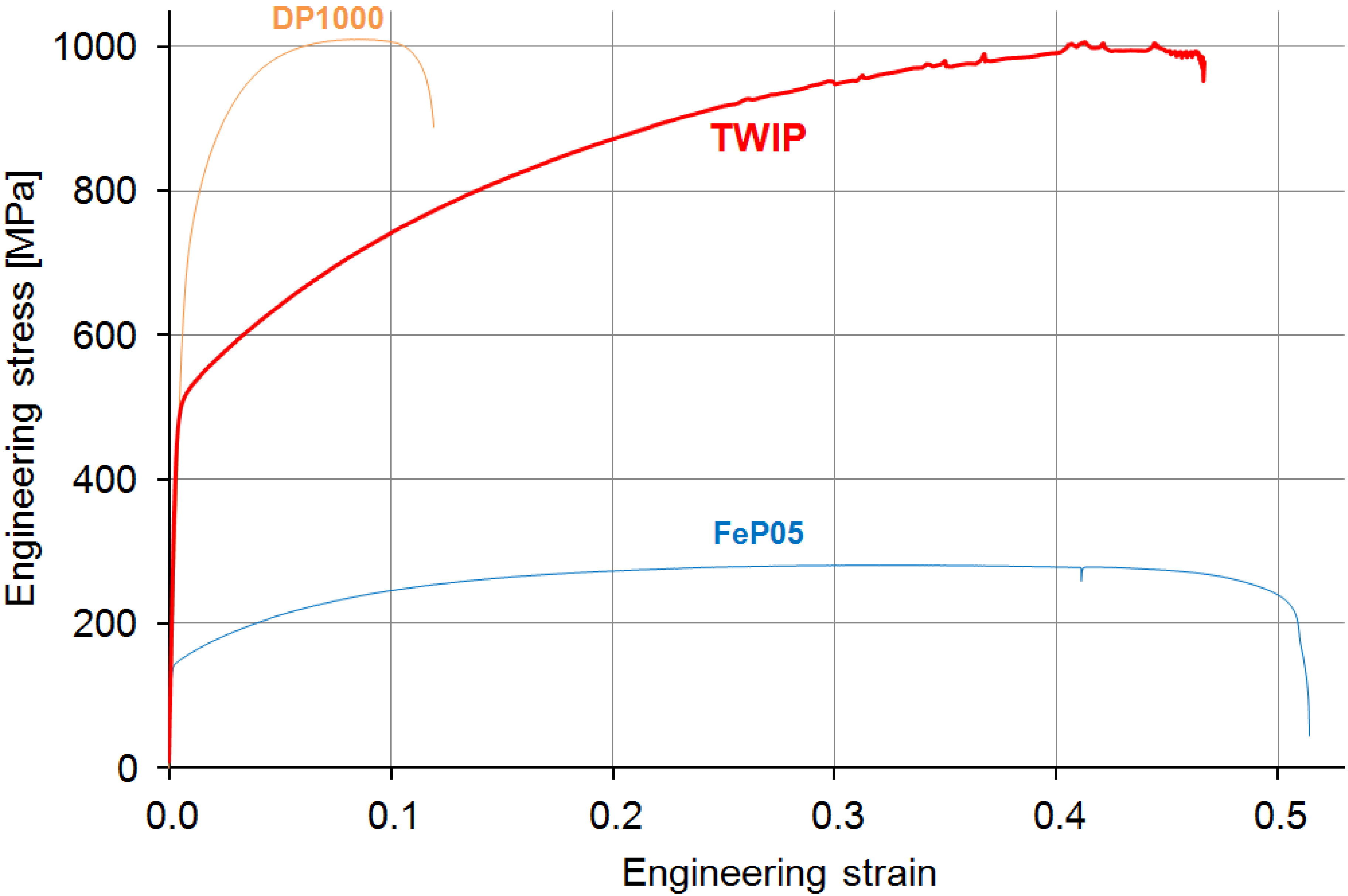
- TWIP: TWinning Induced Plasticity
- Industrial sheets (used for car-body parts, not yet commonplace)
- Fully austenitic (OM and XRD), 3 µm grain size, banding (OM)

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

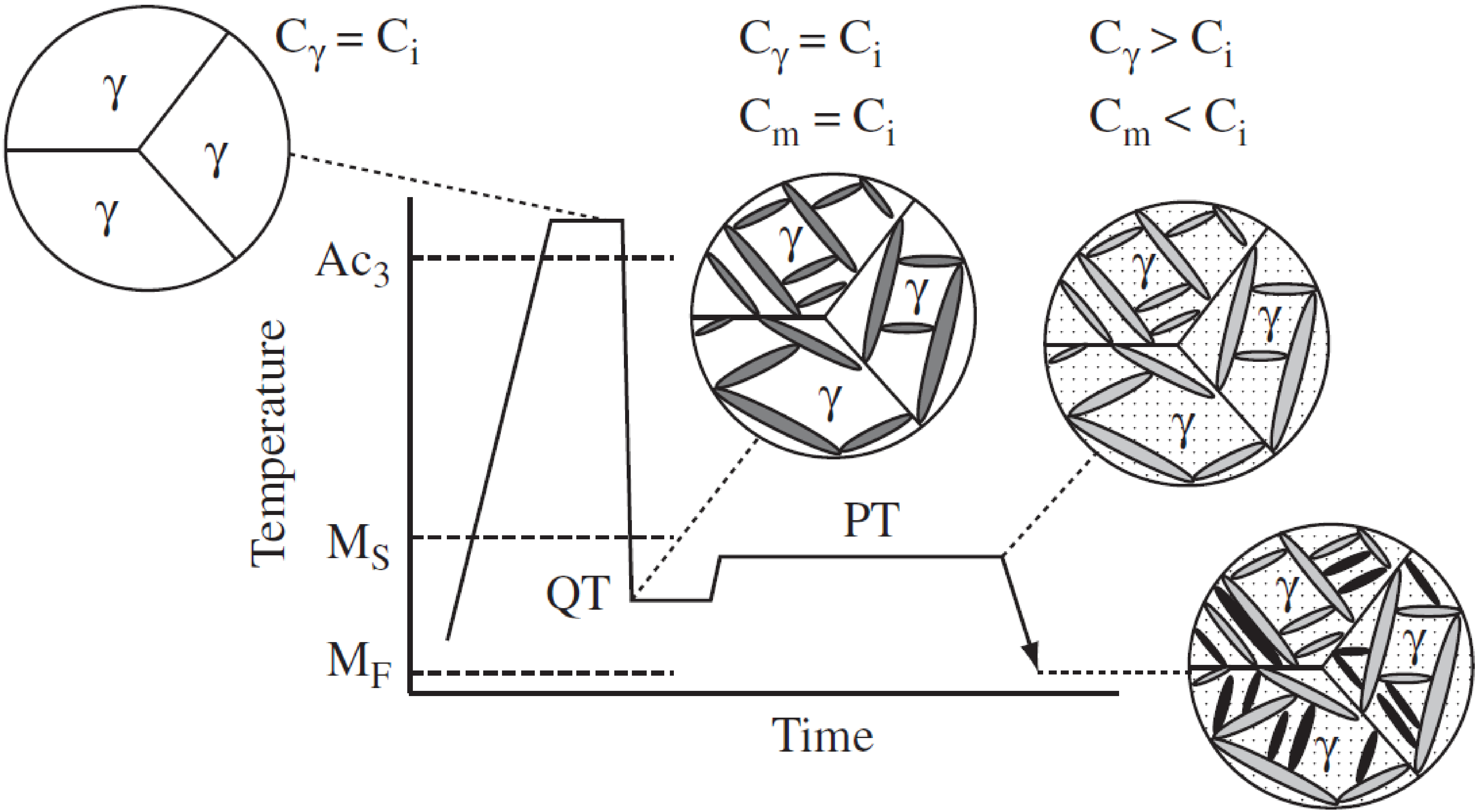


OM, etchant: 1ml HNO_3, 2 ml HCl, 3 ml glycerol

TWIP Steel - Tensile testing



Q&P steel - The Quenching & Partitioning concept



G. Speer et al., Mater. Res., 8 (2005) 417-423

Q&P steel – Experimental alloys & heat treatments

✓ Ingot casting with 3 different compositions:

	C	Mn	Si	Mo	Al	P	S	B	A_{c1}	A_{c3}
"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

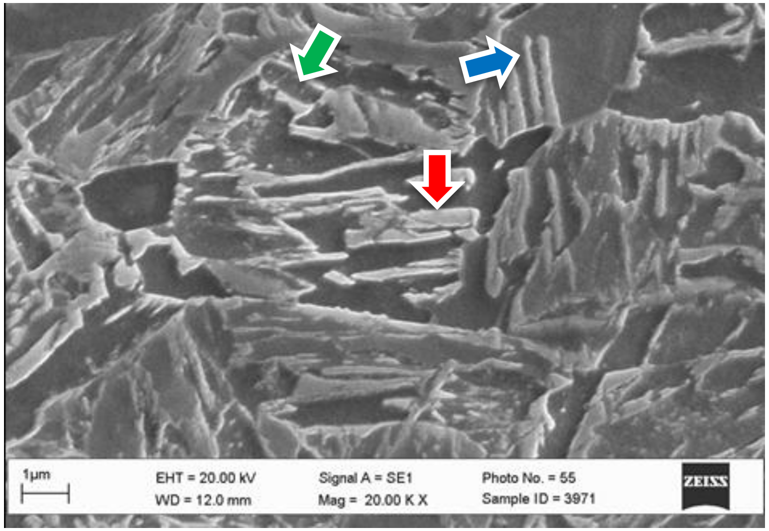
✓ Q&P heat treatment with 9 different schedules (*):

		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.

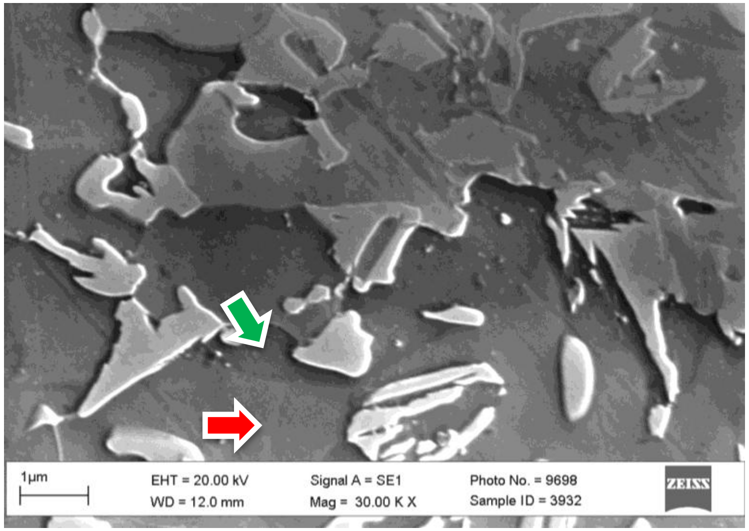
Q&P steel - Microstructural constituents

Si-Mo-3



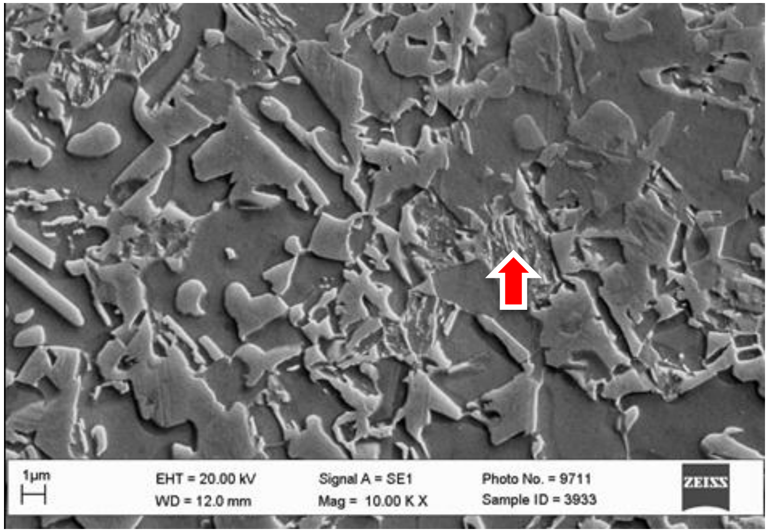
Lath martensite, bainite, austenite

Si-1



Intercritical and epitaxial Ferrite

Si-Mo-1



Tempered martensite

Si-Mo-1

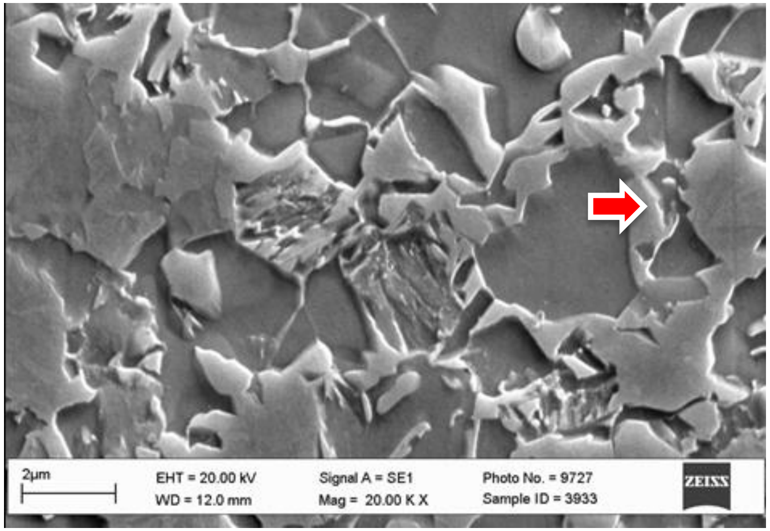


Plate Martensite

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

Q&P steel - Microstructural constituents

Si-3

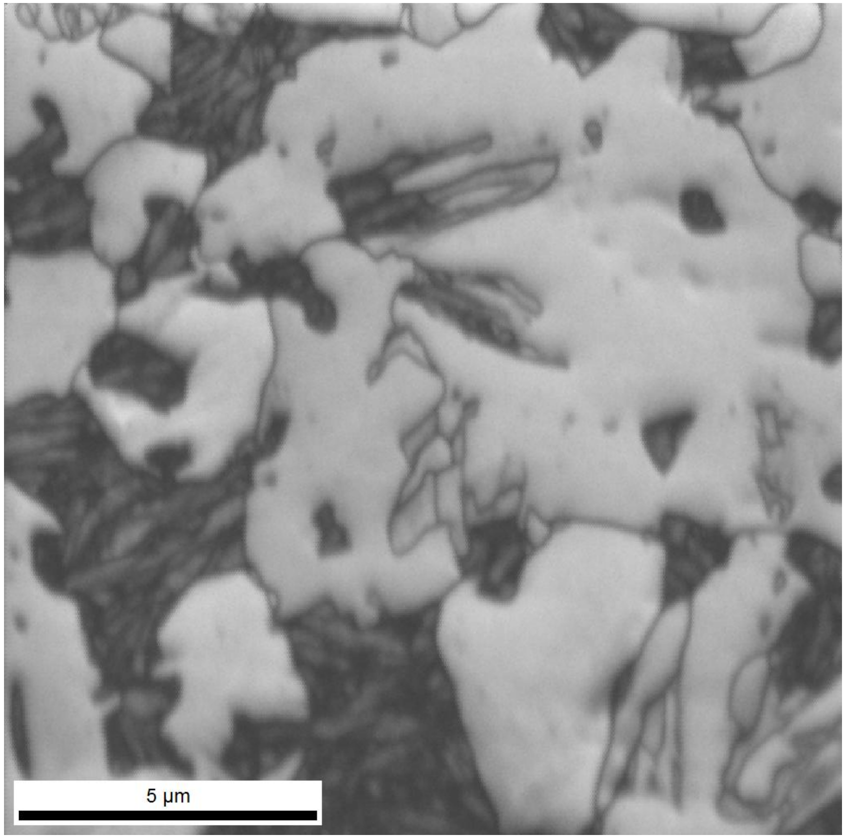


Image quality map

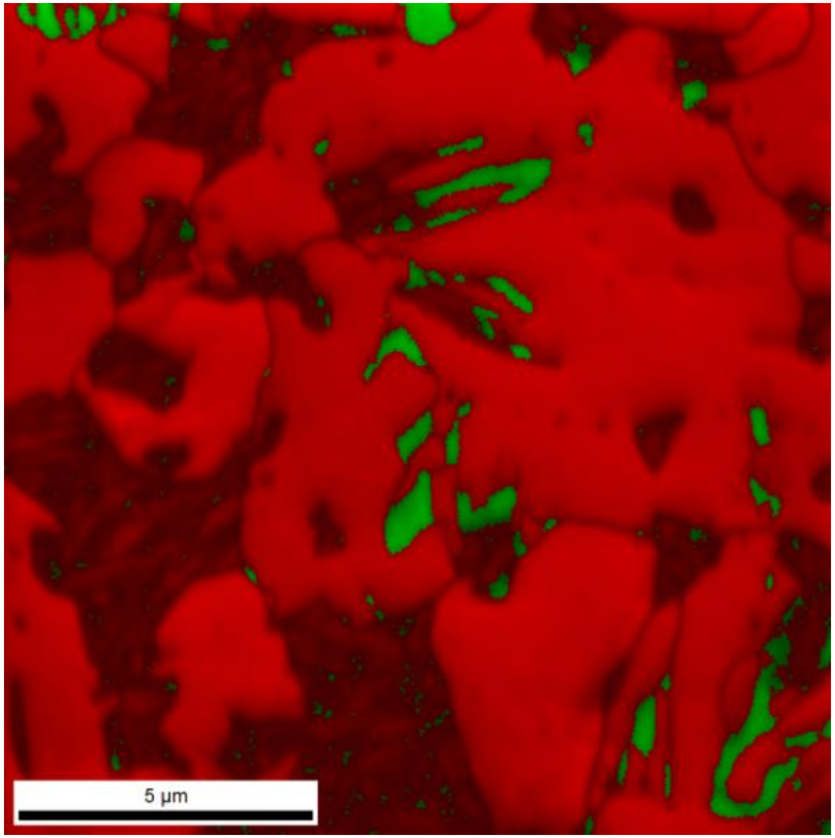
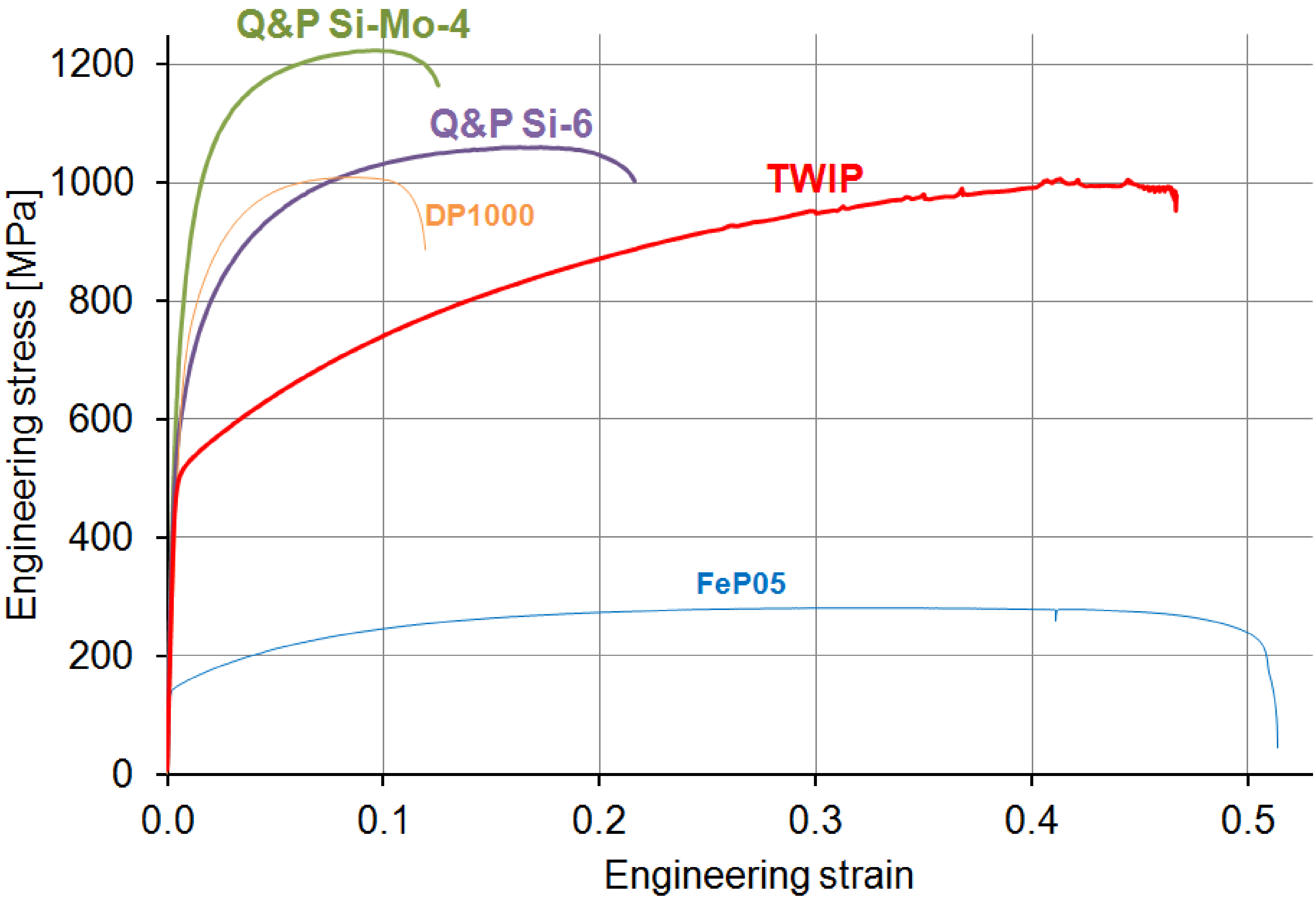


Image quality map (brightness)
+ **BCC** / **FCC** phase map (color).

Q&P steel - Tensile tests results & steels selection

Results [HV1, MPa, %]		Q&P schedule 1	4	5	2	3	6	7	8	9
"Si"	γ	7.4	3.5	8.1	6.4	6.0	<2	<2	<2	<2
	HV1	272	276	244	270	261	233	256	376	389
	UTS	947	1067	938	949	1021	**1071**	1163	1153	1146
	YS	362	404	372	373	584	**636**	503	778	770
	El.	12.0	19.5	22.0	17.9	19.3	**19.8**	15.1	10.8	12.5
"Si-Mo"	γ	2.7	3.5	7.2	6.4	5.7	n. a.	<2	<2	<2
	HV1	347	373	337	358	418	380	445	444	435
	UTS	1159	**1228**	1122	1125	1294	1266	1400	1318	1388
	YS	513	**685**	797	743	1178	1126	1041	1086	1143
	El.	9.2	**13.3**	17.1	17.5	8.9	7.3	7.1	6.2	6.8
"Al"	γ	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		
	El.	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

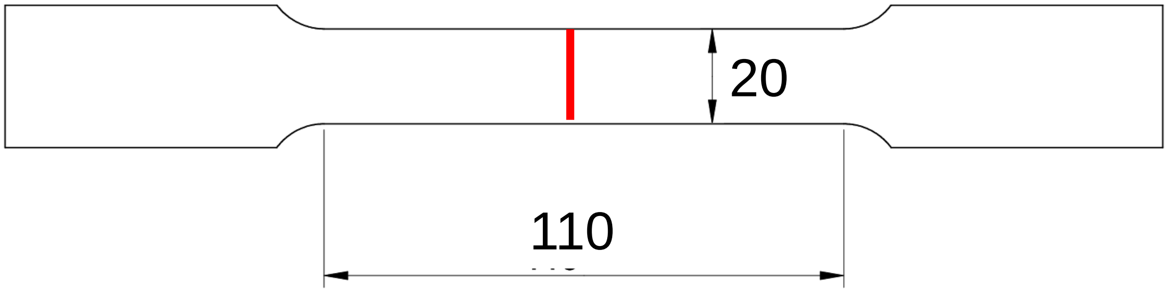
Speed: 0.8 m/min (Q&P) or 0.6 m/min (TWIP) - Current: 80 A - Argon

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.

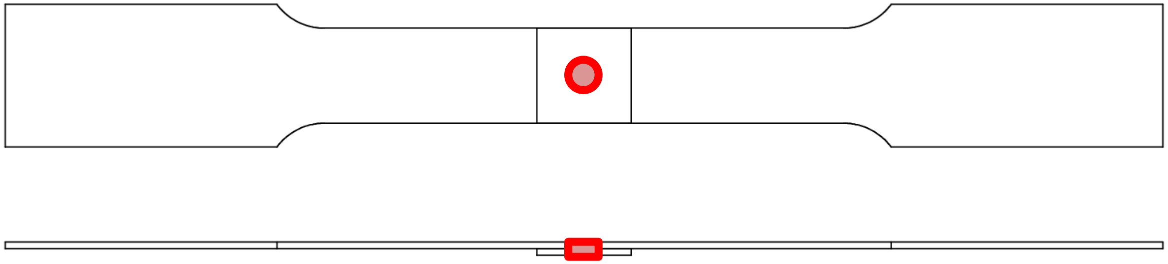


RSW - Resistance Spot Welding

Welding of homologous sheet specimens

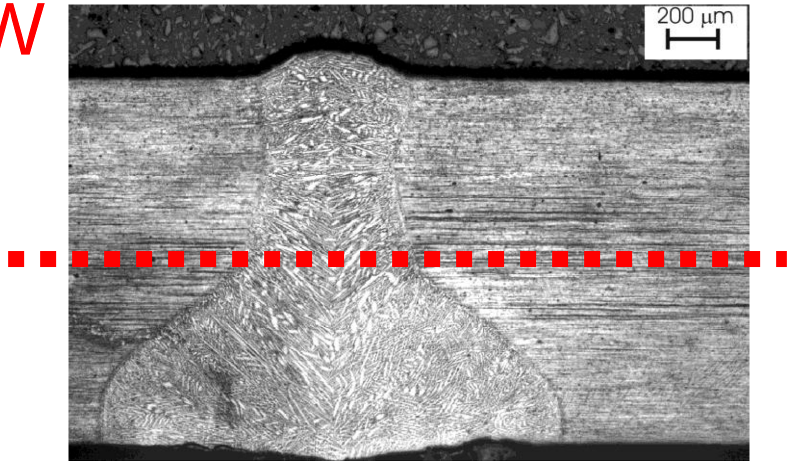
Spot radius: 3 mm - Force: 3.5 kN - Time: 260 ms - Current: 7 kA

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

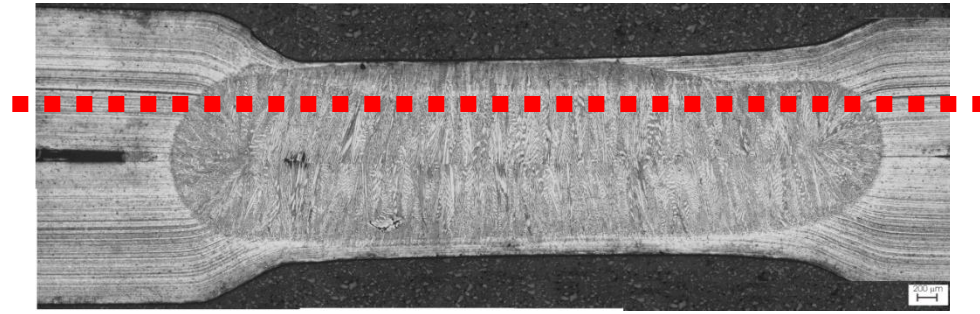


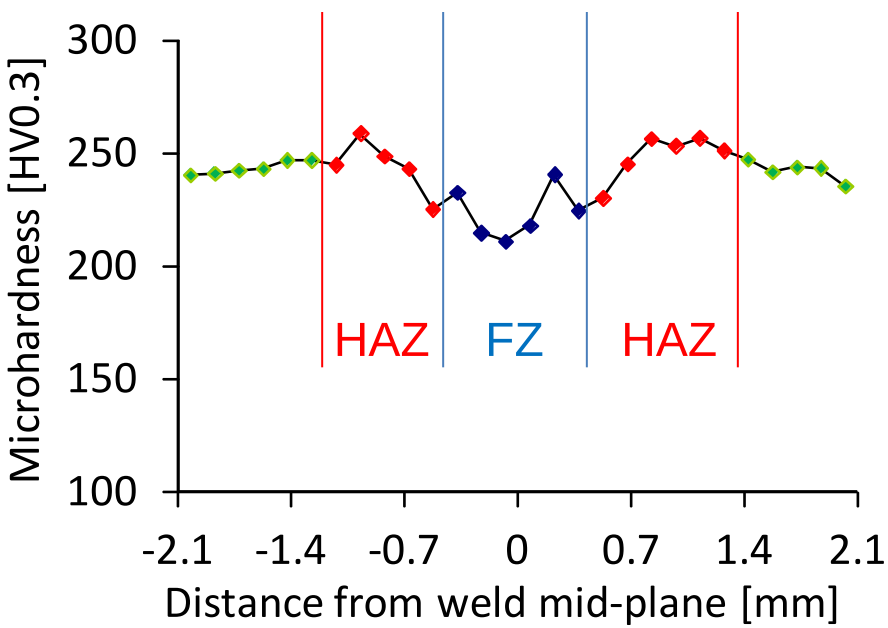
Welding tests – microstructure and hardness

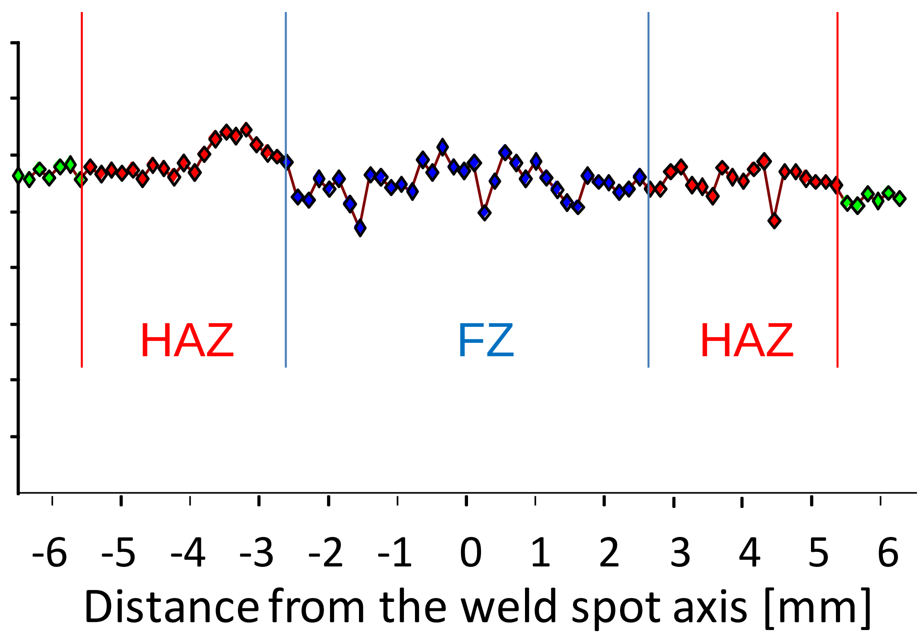
s-LW



RSW

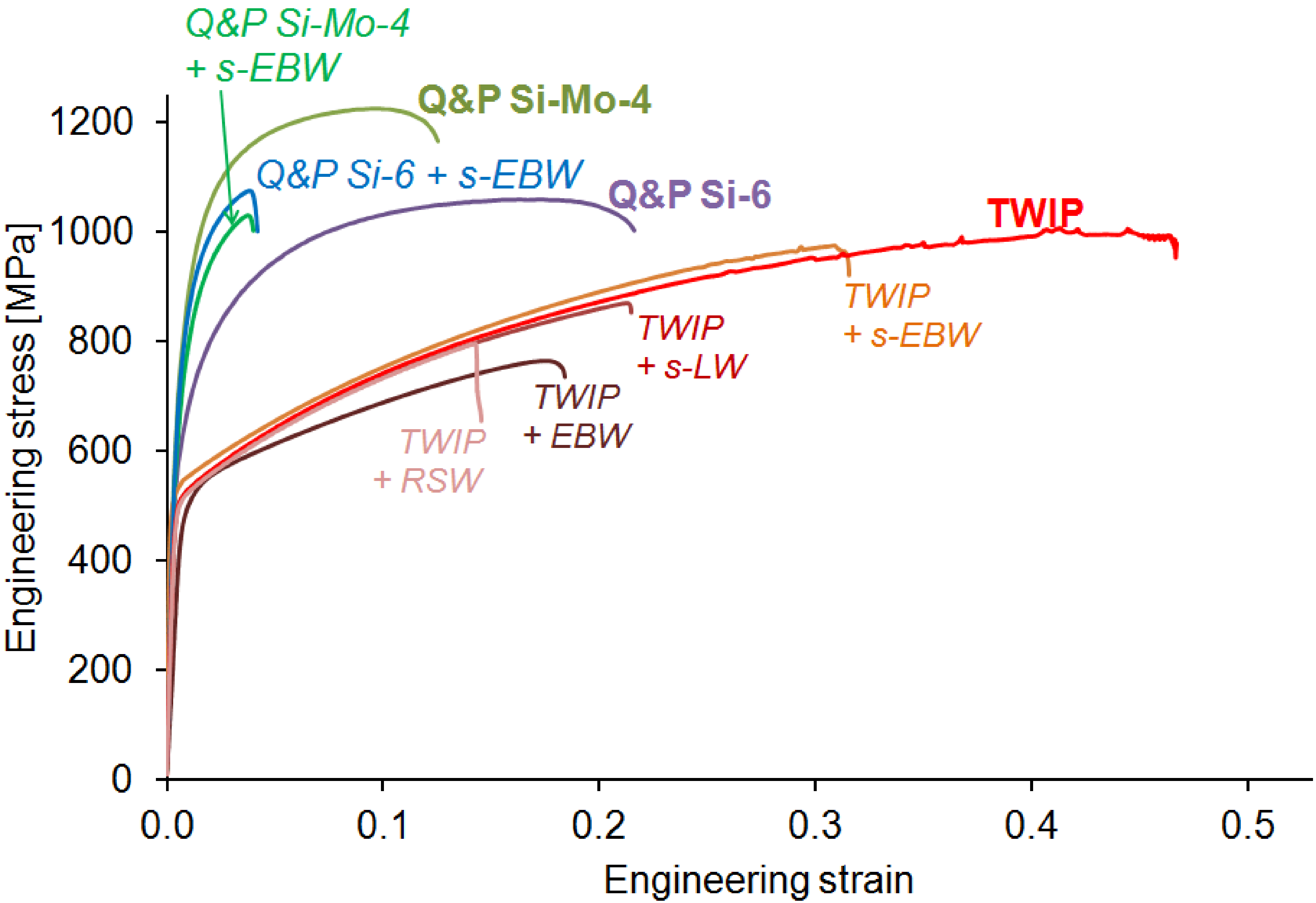




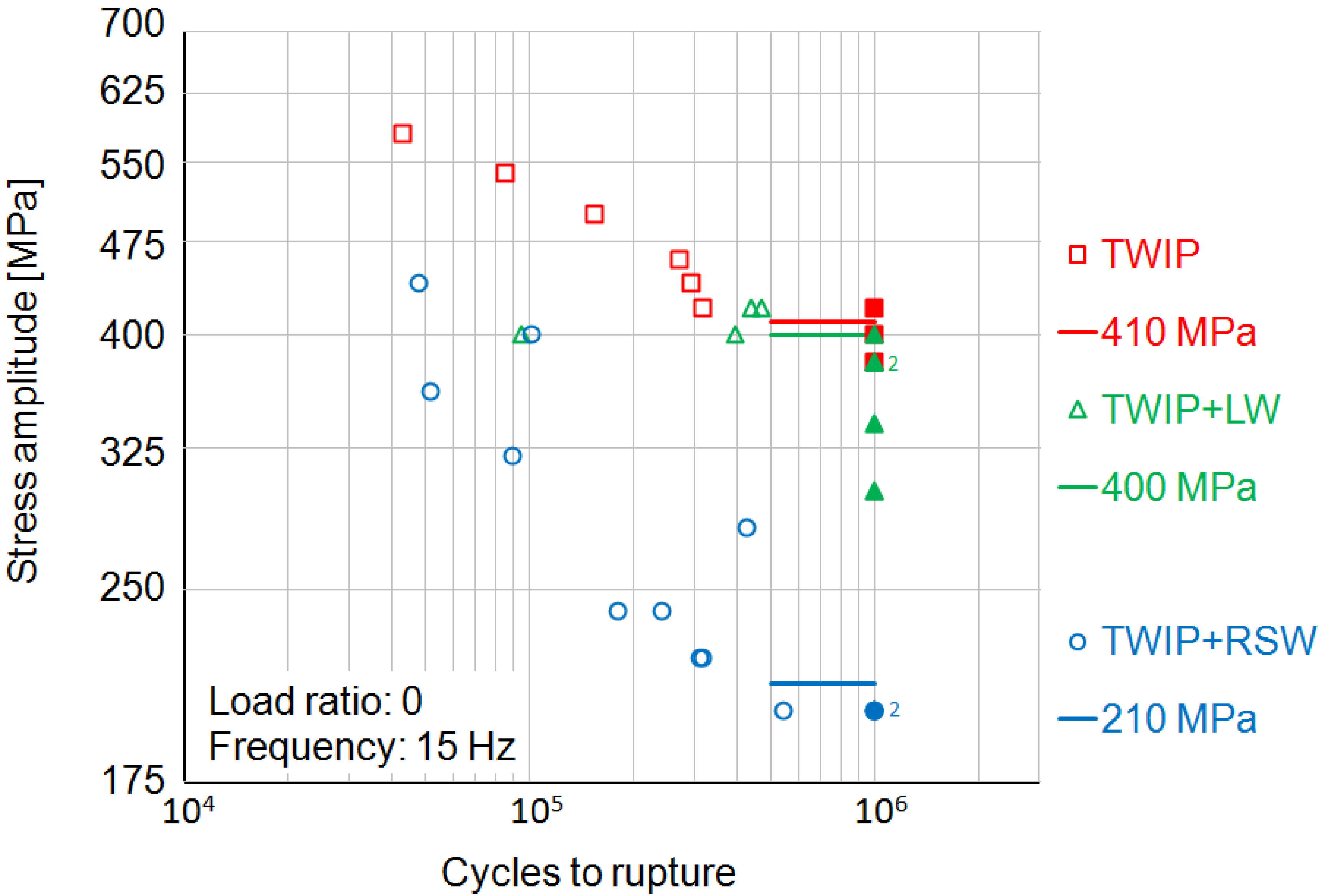


Etching: 10 ml HNO_3, 20 ml HCl, 30 ml glycerin

Welding tests – tensile curves



Fatigue tests – 1 million cycles fatigue strength
Staircase method



Conclusions

- The examined, industrial, high-Mn TWIP steel exhibit a fully sustenitic 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!

Acknowledgements: this work was financed by the *Italian Government* (contract number 2008PSH7YZ); the TWIP steel was procured by *Centro Ricerche FIAT, Torino, Italy*; the Q&P experimental heats and heat treatments were performed by *Riva Acciaio, Lesegno (CN), Italy*.