Fatigue behavior of Dual-Phase and TWIP steels for lightweight automotive structures

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Overall aims

- To characterize and compare mass-produced (*Dual Phase*), innovative (*TWIP*), and experimental high strength steels for car weight reduction

- To facilitate the industrialization of these new steels, with regards to both production processes and service requirements

- To study these steels fatigue crack growth behavior, which may in future be considered in the car-body design and verification, in pursuit of further weight reductions, as it now happens in aeronautic design

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)

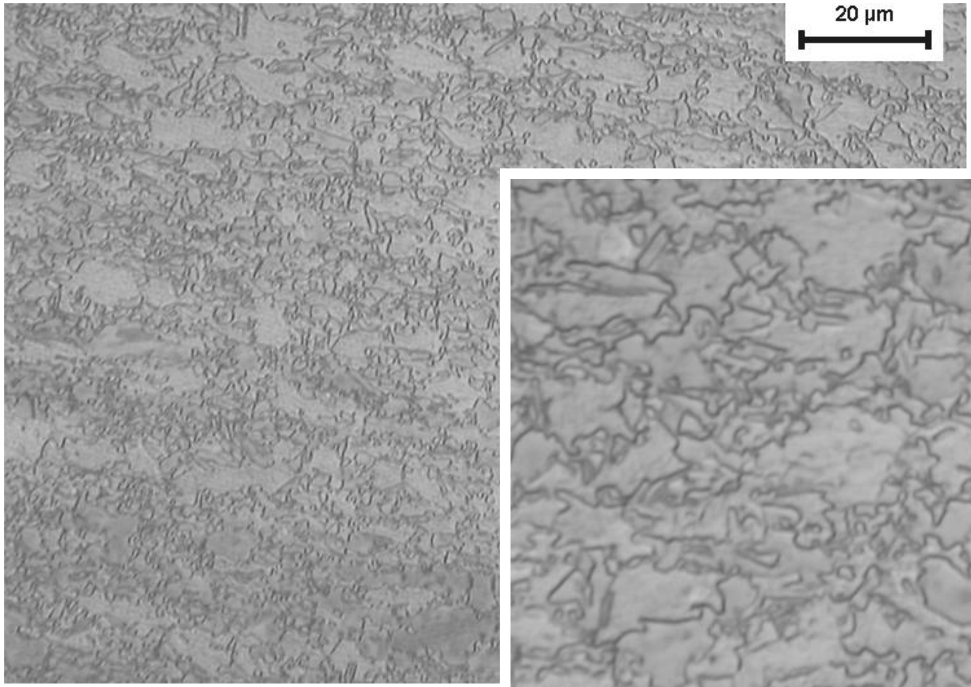
Most common overall production cycle

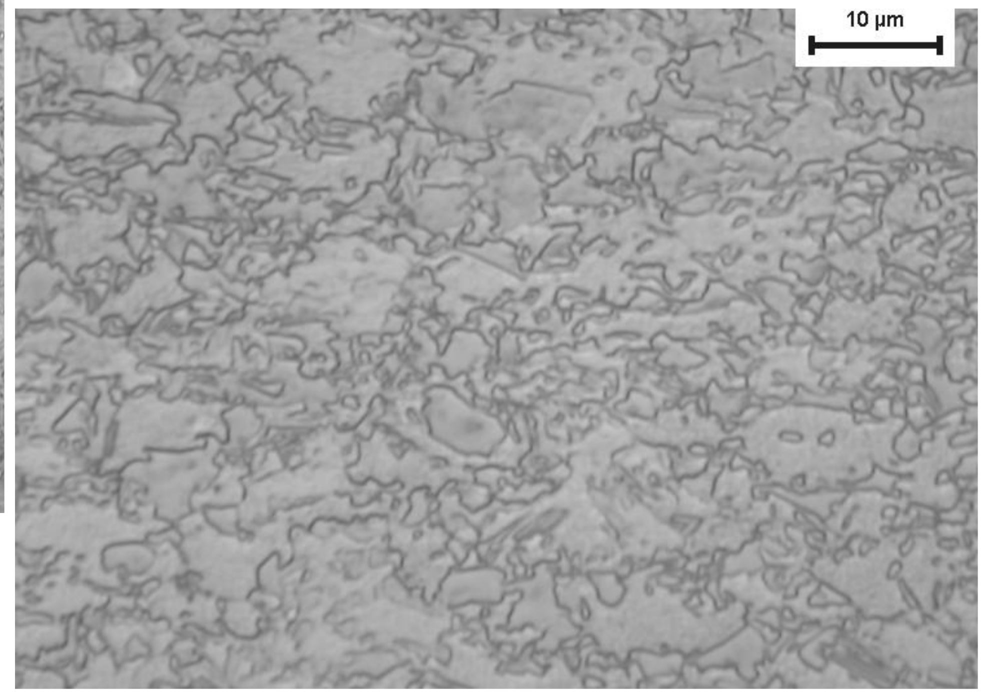
- High-strength weldable steel sheets are made by:
  - continuous casting
  - hot rolling
  - cold rolling
  - continuous final heat treatment
  - protective coating (Zn)
- Sheets are cold formed to produce car body parts
- Car bodies are assembled by resistance spot welding

*Examined **Dual Phase** (**DP**) steel*

- widely used
- low alloy, ferrite and martensite microstructure
- made by intercritical annealing and quenching after cold rolling

OES, Wt. %	
C	0.18
Mn	2.3
Cr	0.50
Si	0.18
Al	0.034
Nb	0.025
Ni	0.015

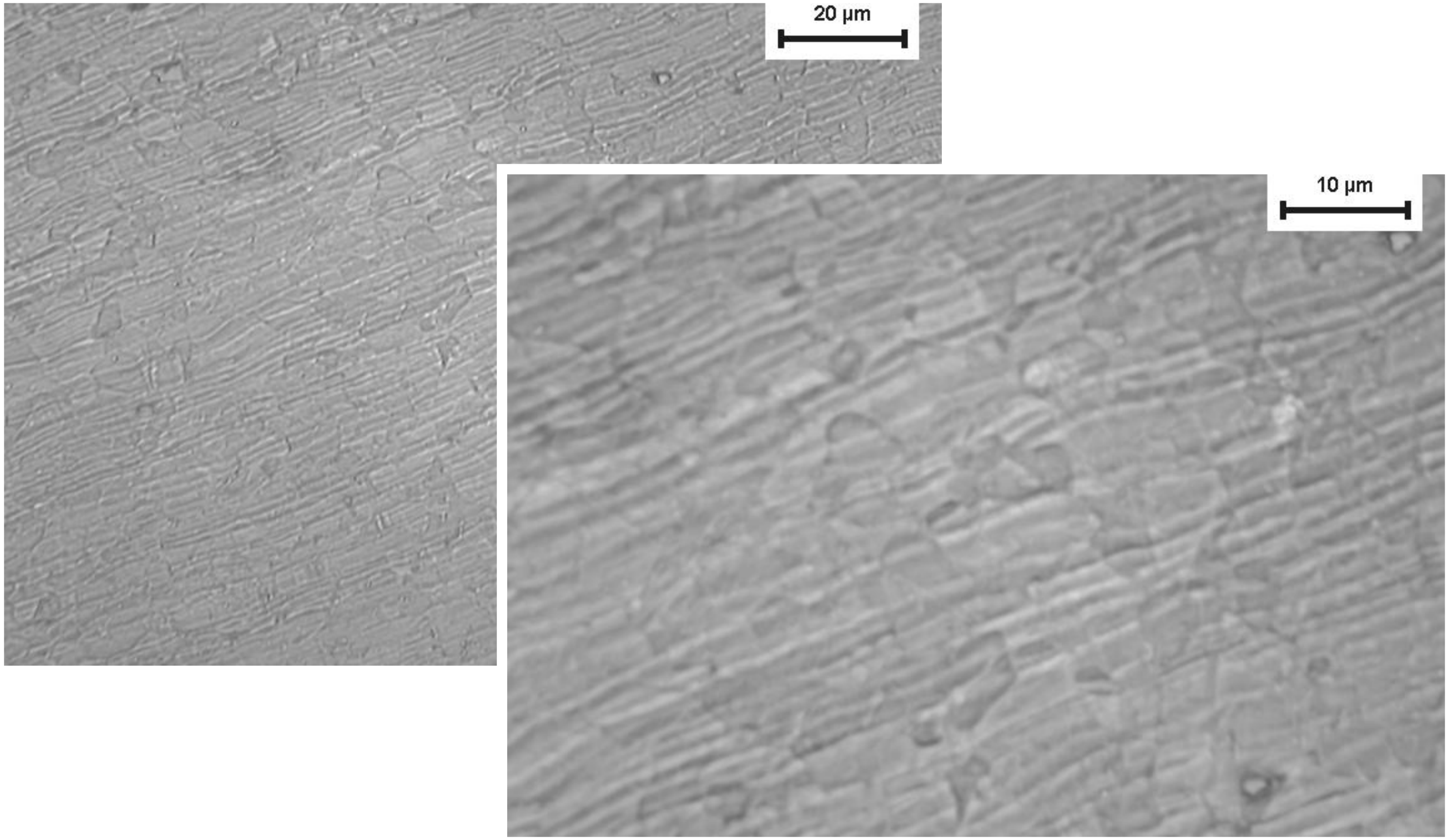




*Examined **TWIP** steel*

- not yet widely used
- ductile, high-Mn austenite strengthened with solute C
- TWinning Induced Plasticity (TWIP) effect

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



Resistance spot welding of TWIP steel sheets (I)

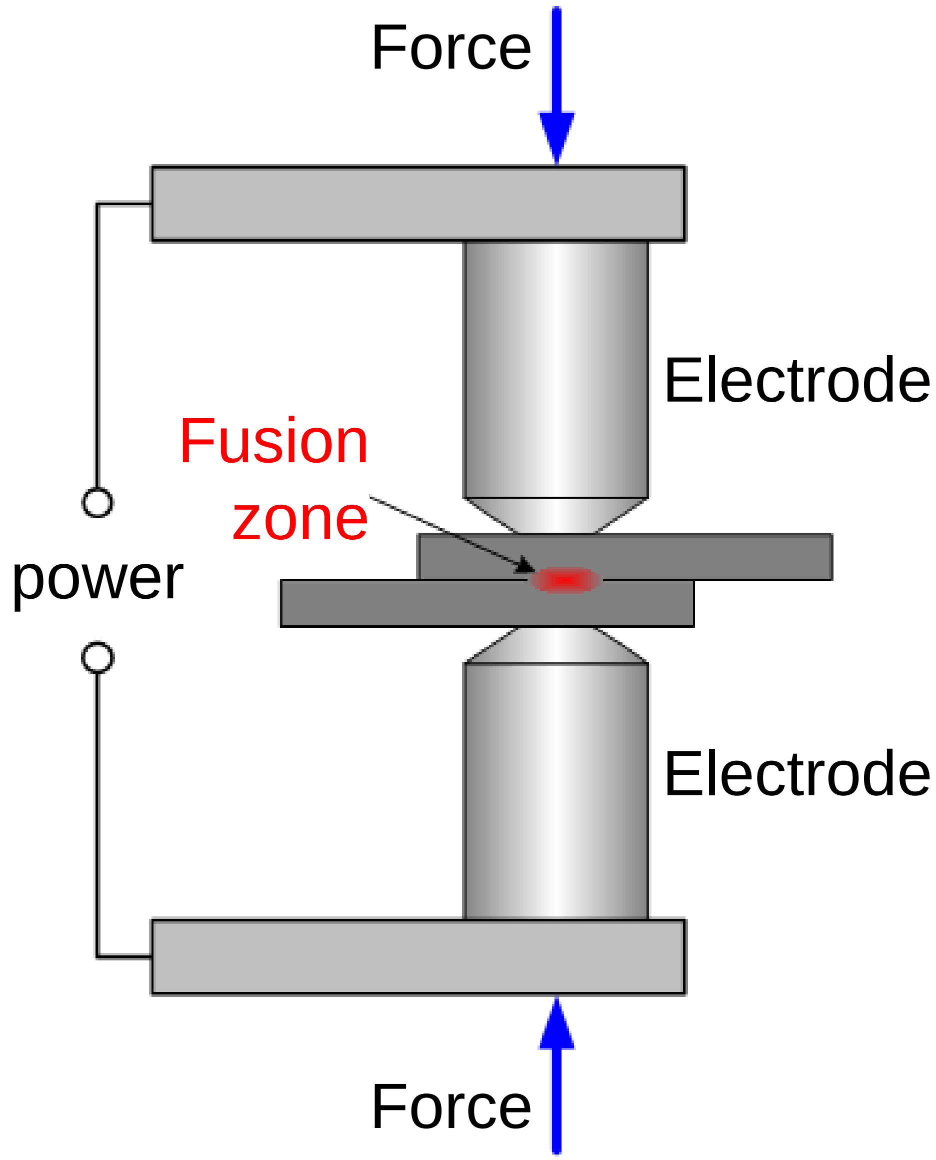
process parameters

Spot radius: 3 mm

Force: 3.5 kN

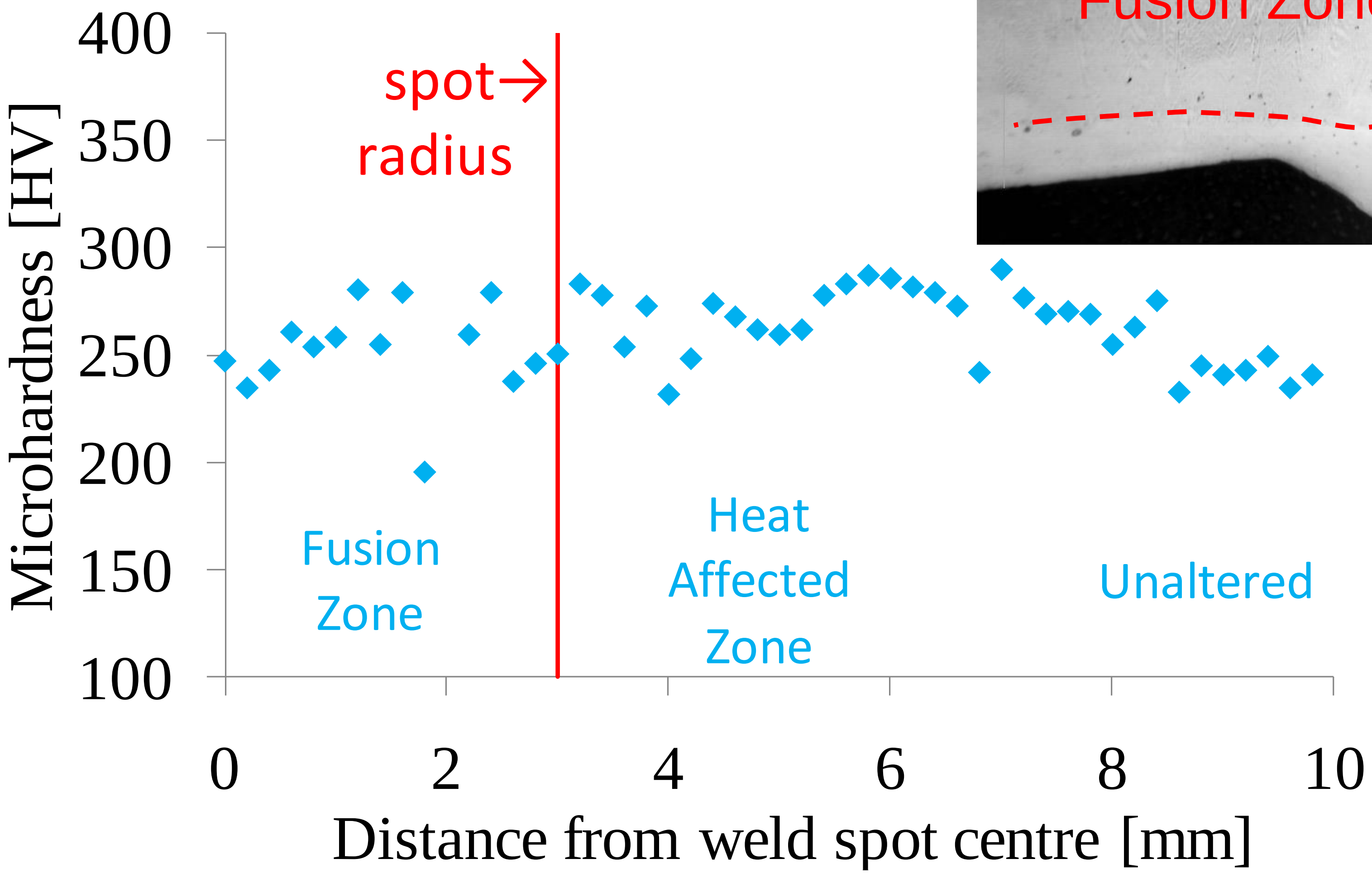
Time: 260 ms

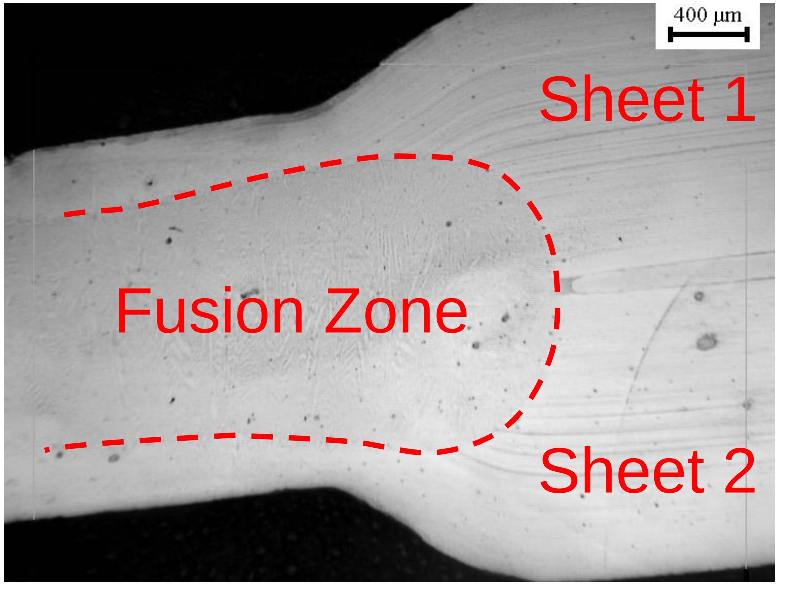
Current: 7 kA



Resistance spot welding of TWIP steel sheets (II)

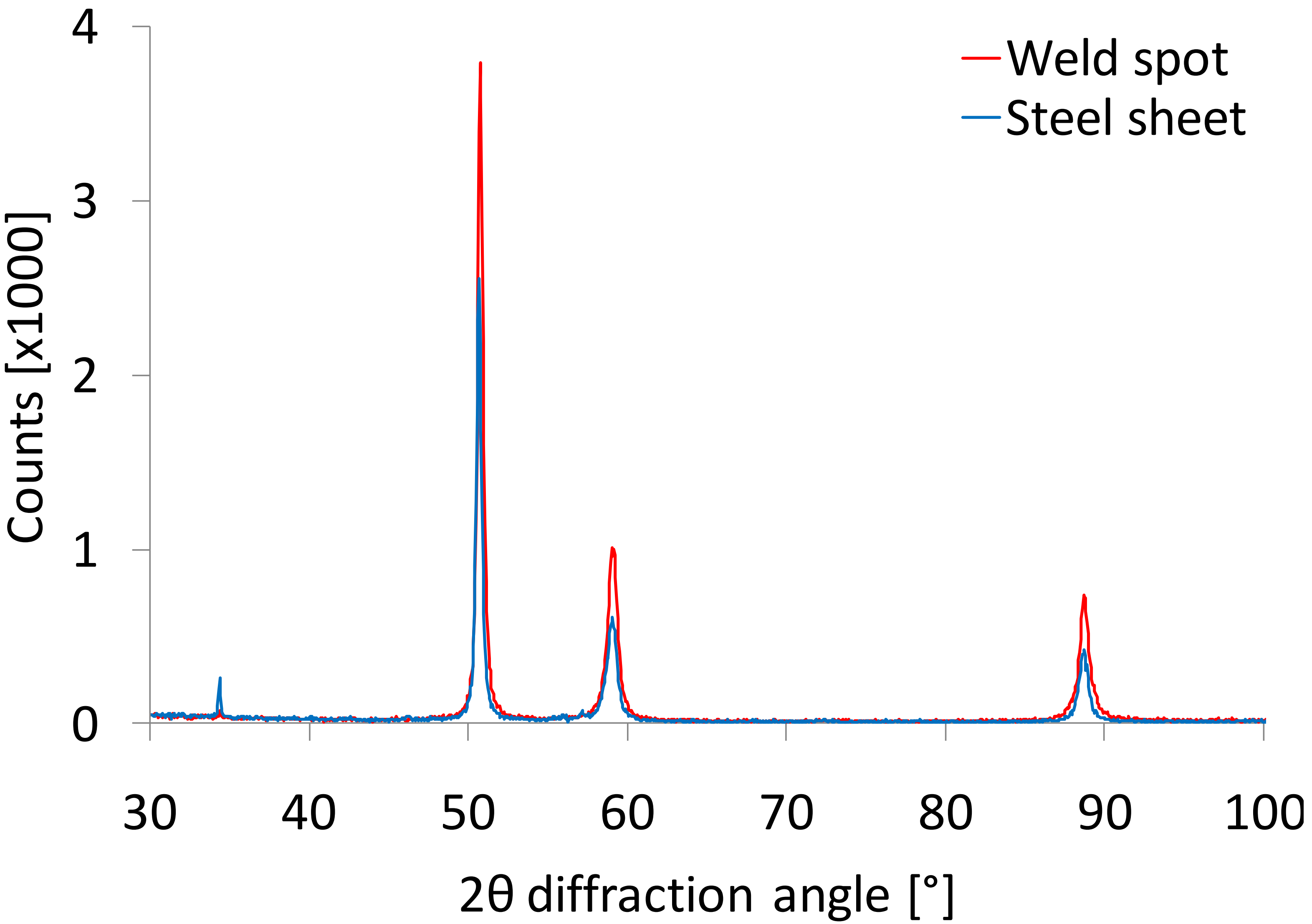
microhardness (no variations)



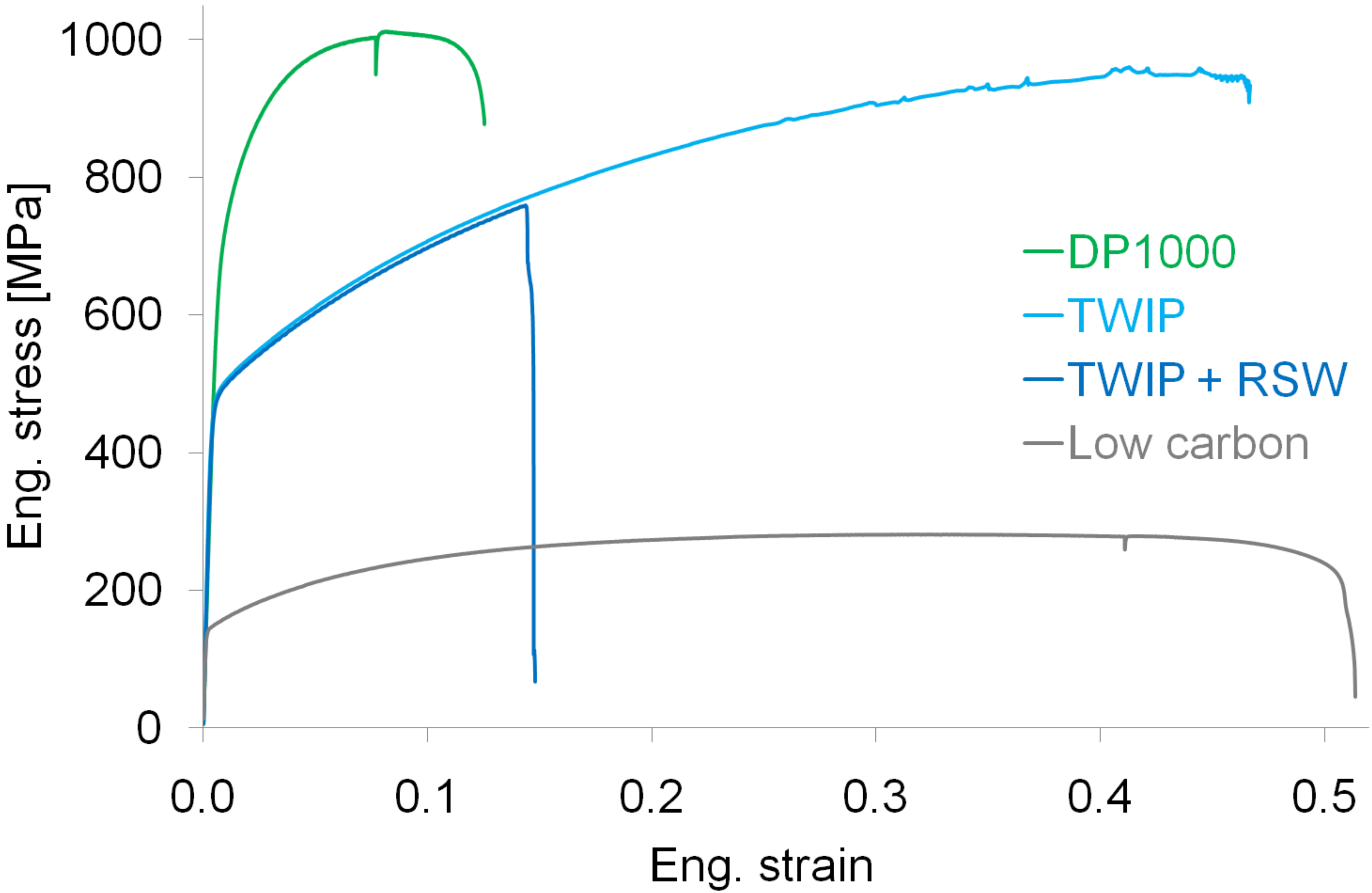


Resistance spot welding of TWIP steel sheets (III)

X-ray diffraction (austenite only)



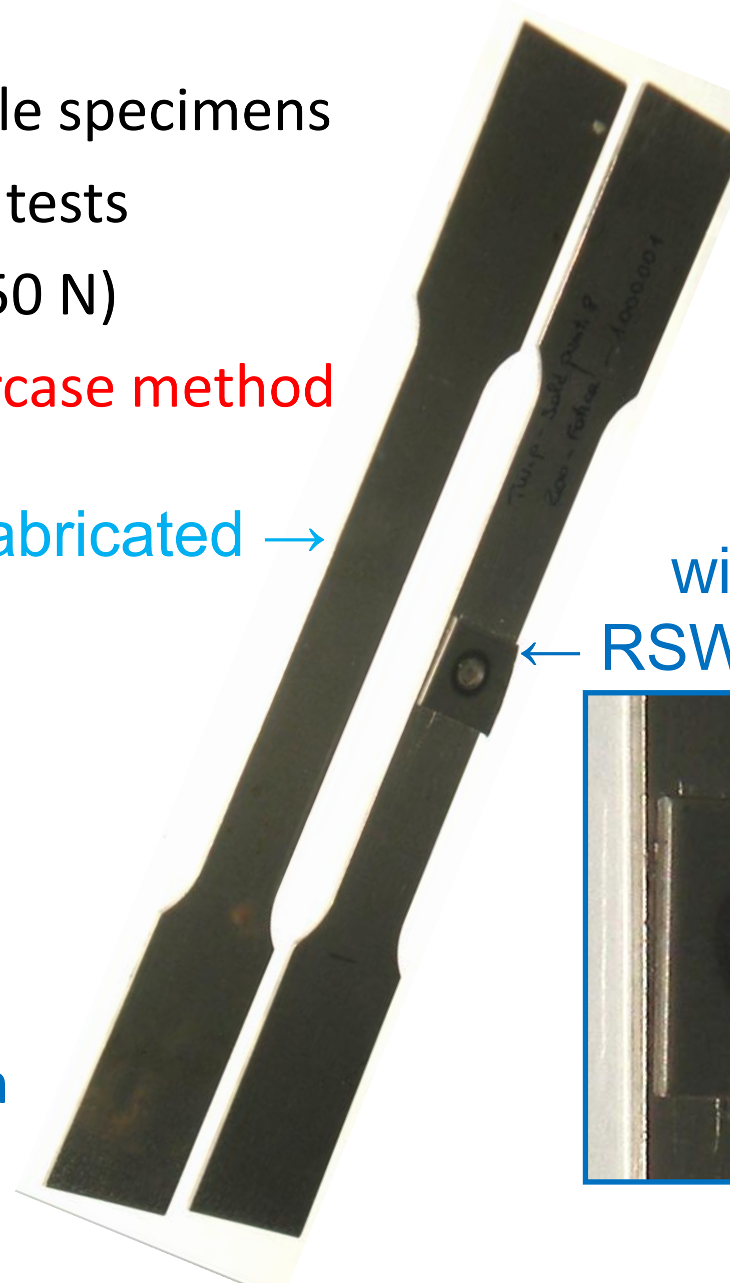
Tensile curves



S-N fatigue - procedures

- ❖ 20 mm wide, full thickness tensile specimens
- ❖ constant load amplitude fatigue tests
- ❖ load ratio ≈ 0 (minimum load = 50 N)
- ❖ 10^6 cycles fatigue limit (σ_D), staircase method

As-fabricated →



with
← RSW spot ↓

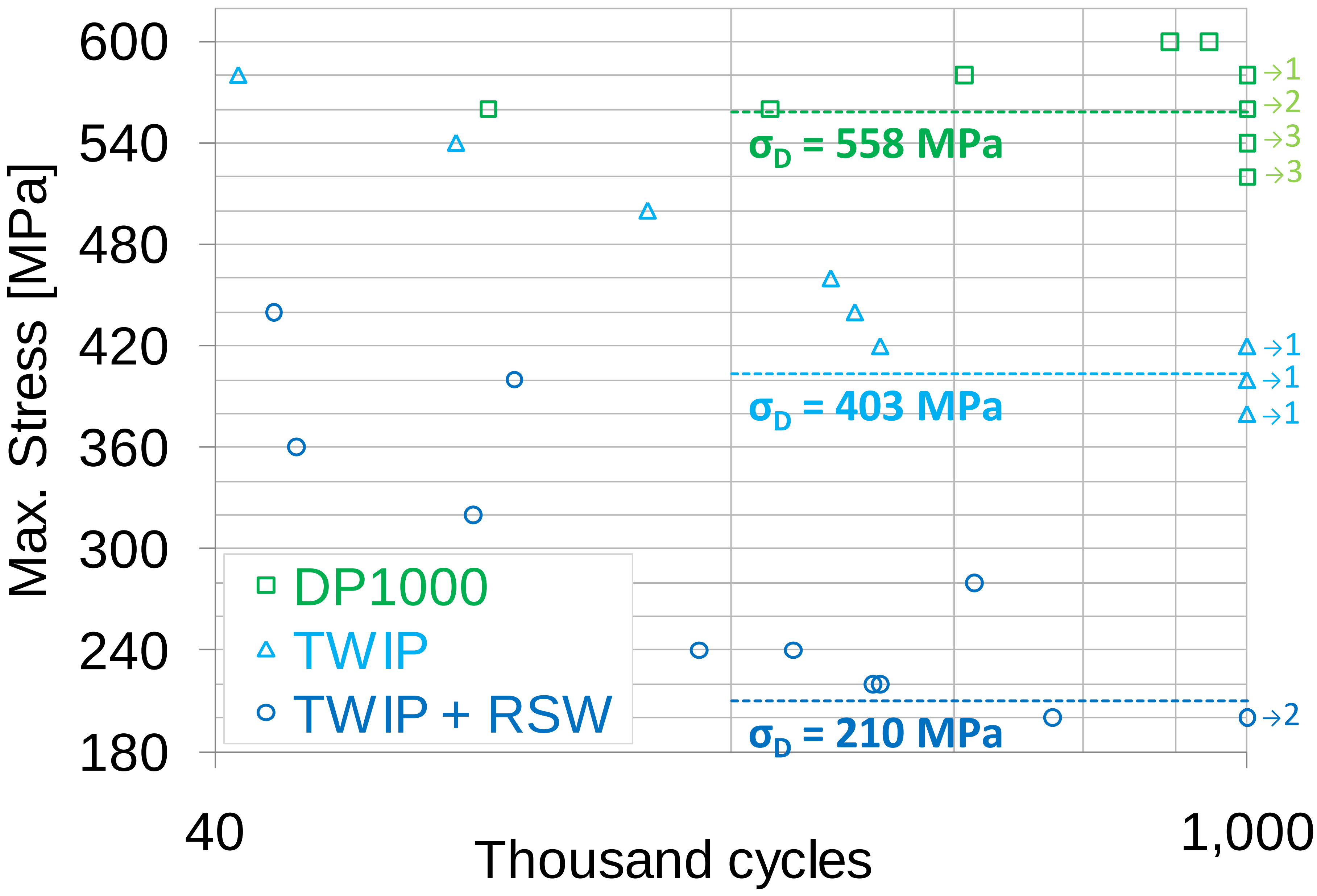
DP1000

- ➢ as-fabricated (with Zn coating)

TWIP

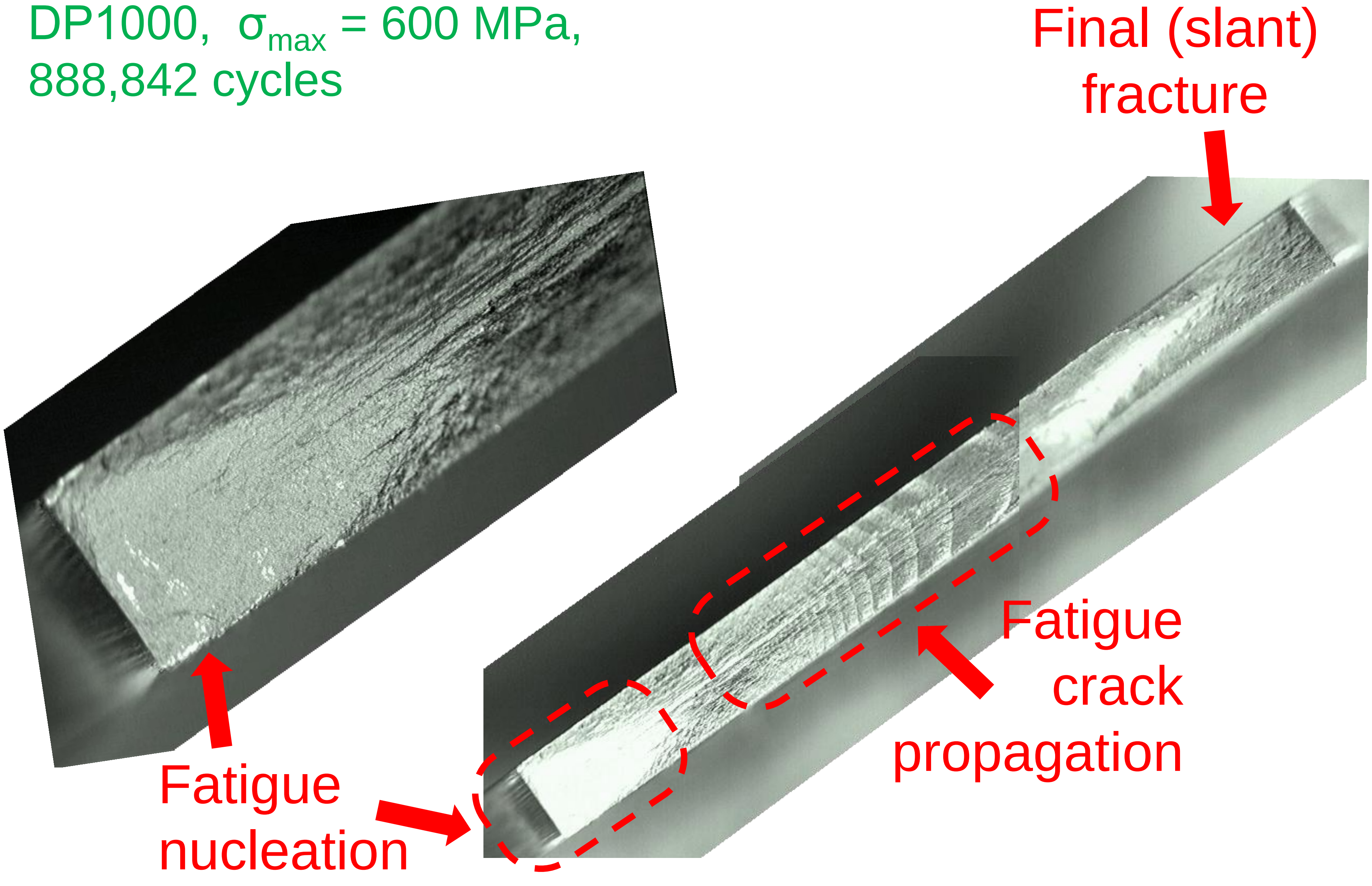
- ➢ as-fabricated (uncoated)
- ➢ with one RSW spot at mid-length (joining a 20 mm sheet square)

S-N fatigue - results



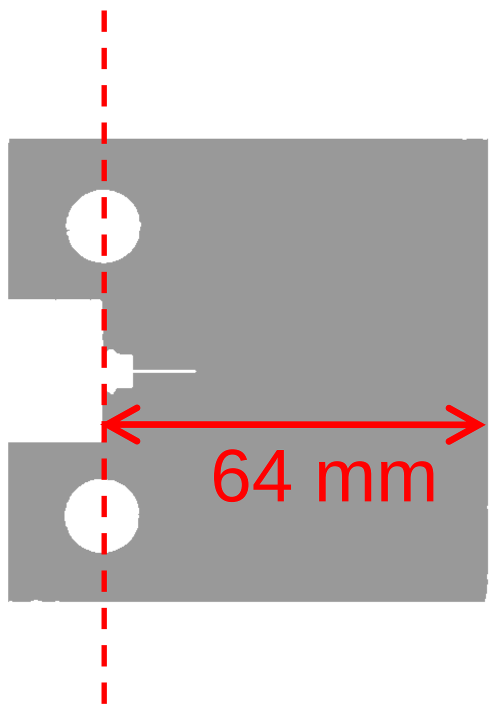
S-N fatigue – optical fractography

DP1000, σ_{max} = 600 MPa,
888,842 cycles

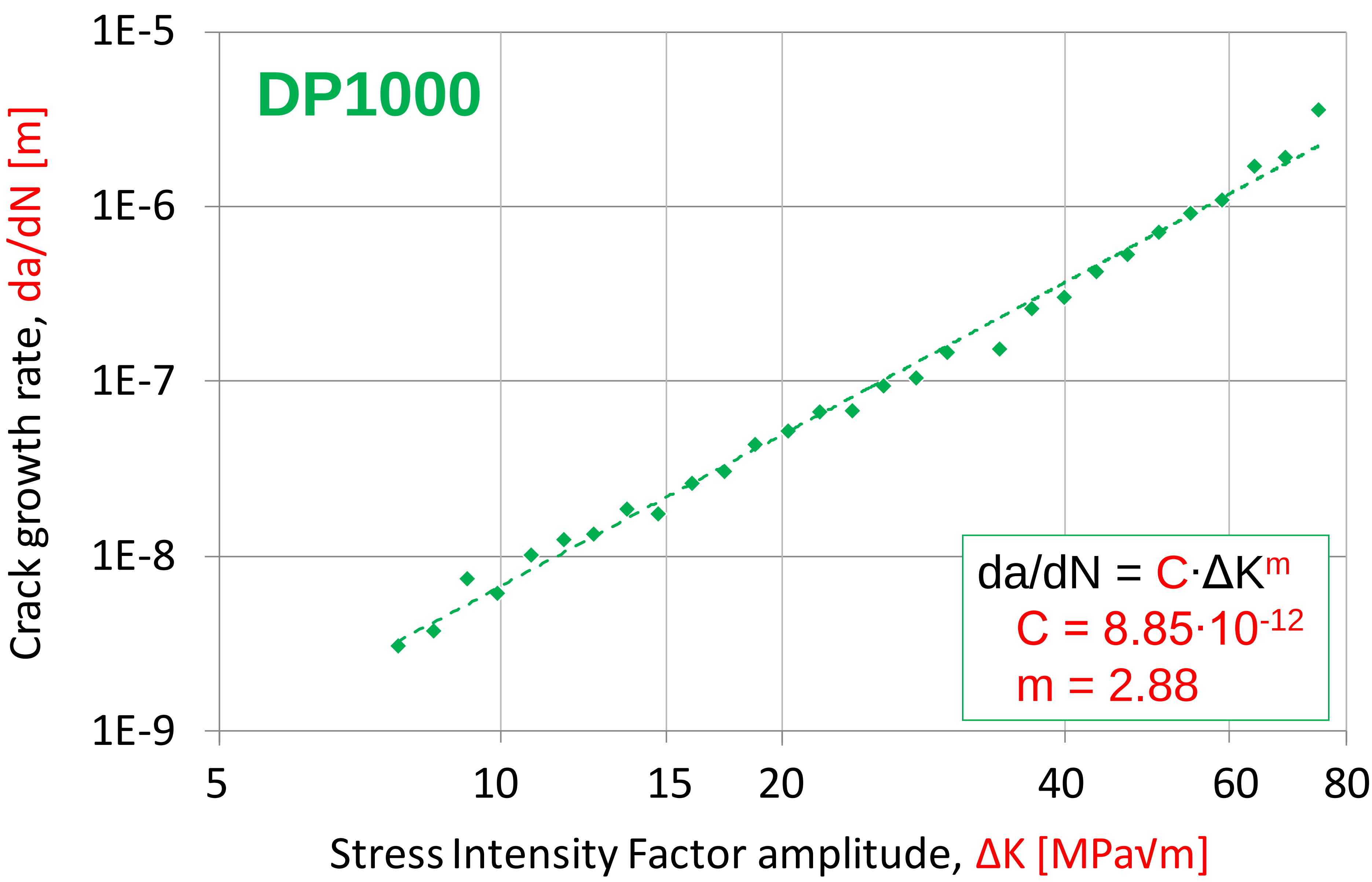


Paris fatigue - procedure

- polished Compact Tension (CT) specimens
- width W=64 mm, thickness B=1.7 mm, B/W≈ 1/38
- pre-cracking & fatigue crack growth as per ASTM E647
- ΔK-increasing procedure:
  - load-controlled fatigue steps
  - ≈ 0.3 mm crack growth per step
  - ≈ 8% ΔK increase between steps
- Load ratio = 0.1
- Optical crack-length measurements



Paris fatigue - results



Conclusions & Future Work

- The TWIP steel (0.65% C, 18% Mn, 1.5% Al) exhibits remarkable UTS (≈ 950 MPa) and ductility (≈ 50%), but a lower fatigue limit (403 MPa at 1 million cycles) than a dual phase steel with similar strength
- RSW welding spots greatly reduce the TWIP steel strength, ductility, and fatigue resistance, even if the weld microstructure is similar to the base metal
- A Paris plot was successfully obtained for a dual phase steel sheet, notwithstanding the quite reduced thickness
- Further tests are needed for a thorough characterization and comparison of the examined steels

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