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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
- **TW**inning **I**nduced **P**lasticity (**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**

DP1000

- as-fabricated (with Zn coating)

TWIP

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

As-fabricated →

with

← RSW spot ↓

S-N fatigue - results

S-N fatigue – optical fractography

DP1000, $\sigma_{\max} = 600$ MPa,
888,842 cycles

Paris fatigue - procedure

- ❖ polished **Compact Tension** (CT) specimens
- ❖ width **$W=64$ mm**, thickness **$B=1.7$ mm**, **$B/W \approx 1/38$**
- ❖ pre-cracking & fatigue crack growth as per ASTM E647
- ❖ **ΔK -increasing** procedure:
 - load-controlled fatigue steps
 - ≈ 0.3 mm crack growth per step
 - $\approx 8\%$ 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 ($\approx 50\%$), 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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