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Fracture toughness measurements to understand local ductility of advanced high strength steels

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IDDRG 2019

38th International Deep Drawing Research Group annual conference

Enschede, the Netherlands, June 03-07, 2019

iddrg 2019 ENSCHEDE – THE NETHERLANDS

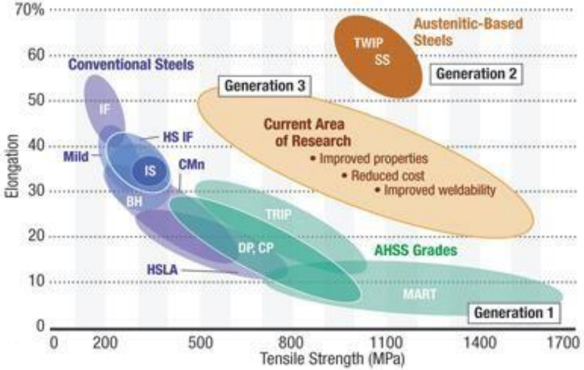
Outline

1. Introduction
2. Materials and experimental procedures
3. Results and discussion
4. Conclusions
5. Further work

1. Introduction

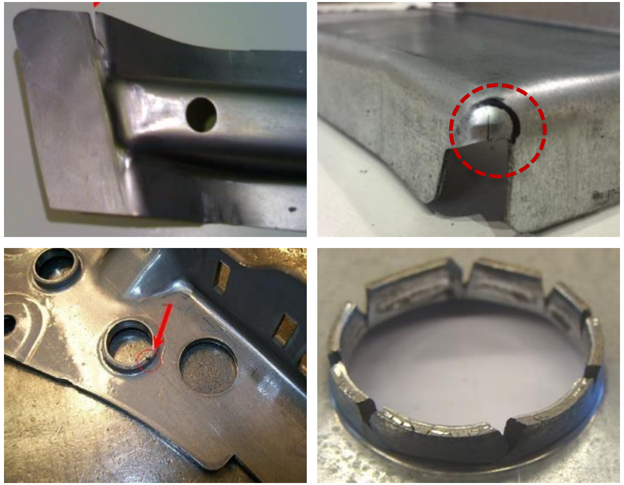
1. Introduction

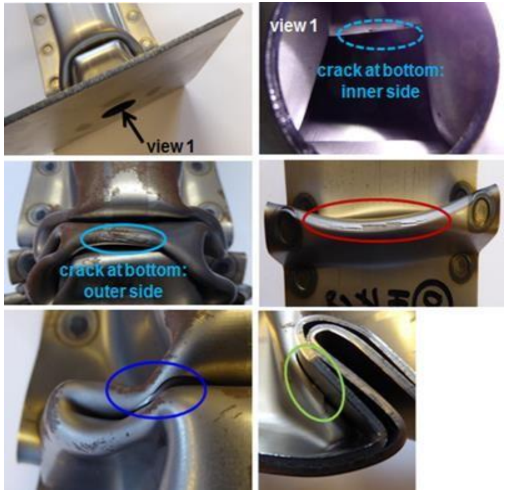
LIGHTWEIGHT AUTOMOTIVE DESIGNS → Advanced High Strength Steels (AHSS)



- HIGH STRENGTH
- GREAT ENERGY ABSORPTION
- GREAT LIGHTWEIGHT POTENTIAL

- LOWER DUCTILITY
- LIMITED FORMABILITY
- CRACKING PROBLEMS (EDGE CRACKING, CRACK FORMATION IN CRASH)



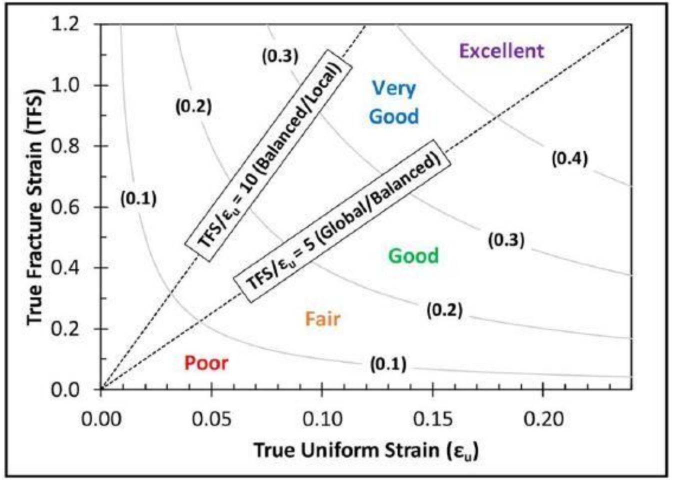


1. Introduction

Formability and fracture characterization of AHSS

Global ductility	Local ductility
• Resistance against necking instability • Deep drawing	• Edge formability • Bending on tight radius • Crash folding behaviour
↓	↓
• Forming Limit Curve (FLC) • Tensile parameters: elongation (uniform and total), strain hardening exponent (*n*)	• True Fracture Strain (TFS) • Z-value • Bending angle (V-bending tests) Fracture toughness

Enhanced formability mappings



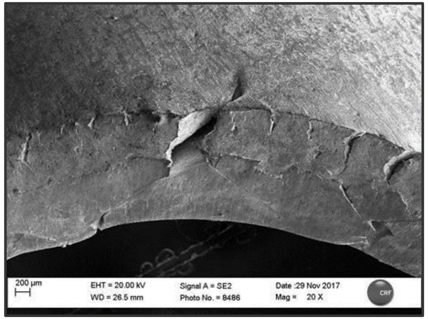
B. Hance. Advanced High Strength Steel (AHSS) Performance Levels. *SAE Technical Paper* 2018-01-0629, 2018.

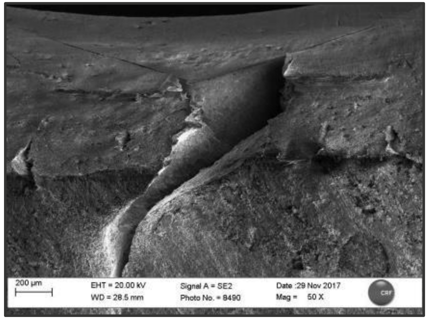
1. Introduction

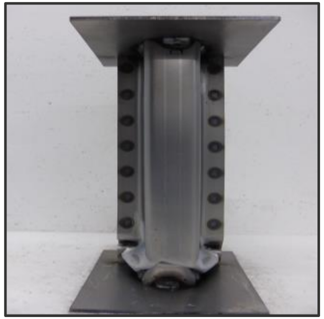
Local ductility → **Cracking related fractures** → **Crack initiation and propagation resistance** → **Fracture toughness**

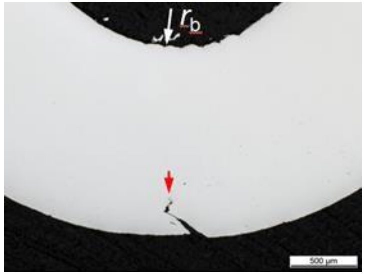
Edge cracking resistance

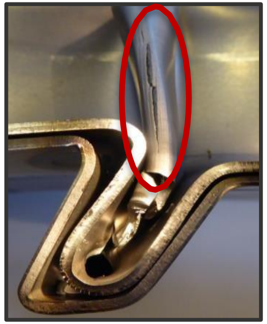
Crash failure behaviour

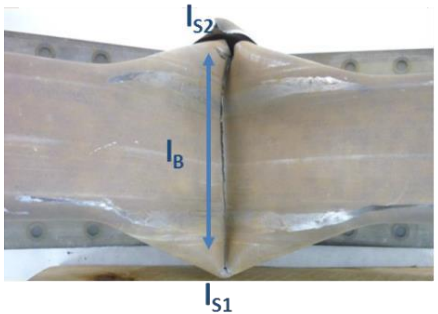


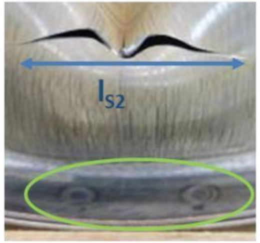








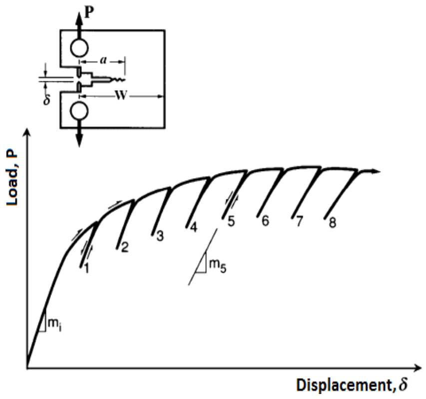




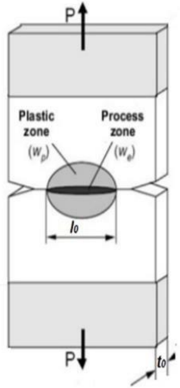
1. Introduction

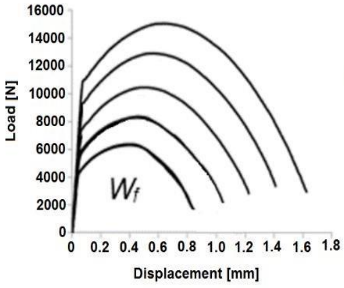
Fracture toughness of thin metal sheets: Elastic Plastic Fracture Mechanics (EPFM)

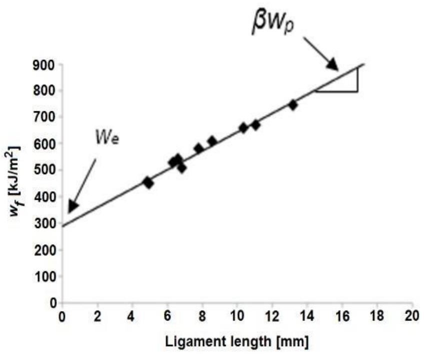
J-Integral



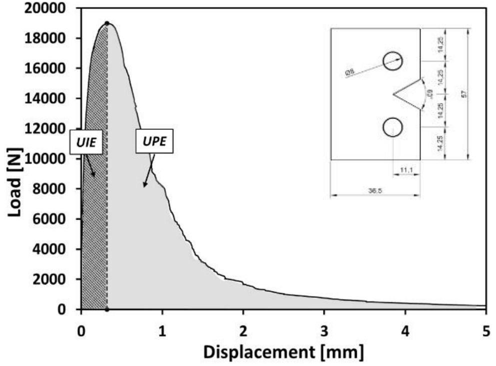
Essential work of fracture (EWF)







Kahn Tear Tests (KTT)



Methodology	Standard	Complexity	Material property
J-integral	ASTM E 1820	COMPLEX	YES
EWF	ESIS Protocol	INTERMEDIATE	YES
KTT	ASTM B 871	EASY	NO

2.Materials and experimental procedures

2. Materials and experimental procedures

Materials

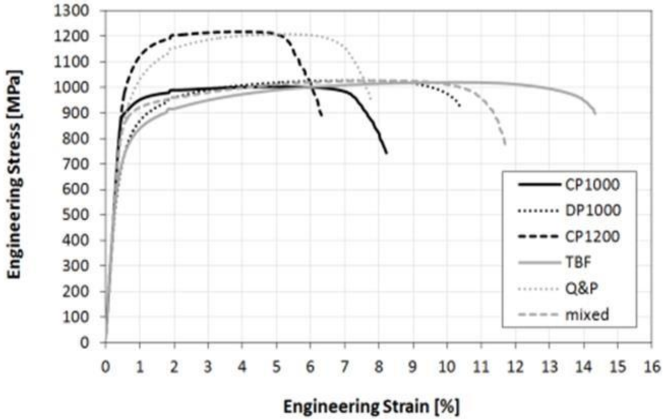
8 AHSS 1000-1500 MPa UTS
thickness= 1.4 – 1.6 mm

1st Gen AHSS

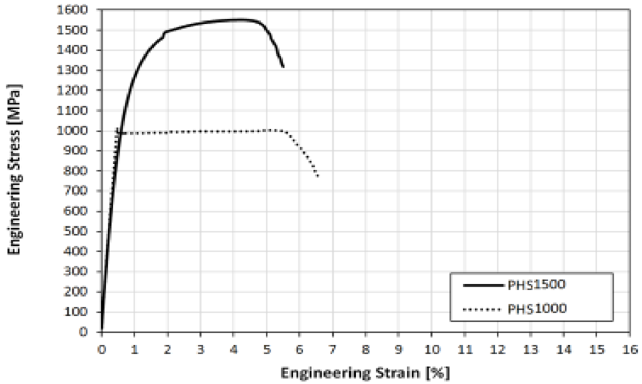
- CP1000
- DP1000
- CP1200
- PHS1500
- PHS1000

3rd Gen AHSS

- TBF
- Q&P
- TBF/Q&P



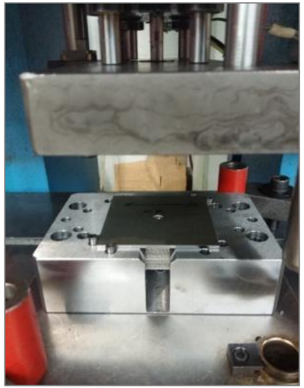
	Thickness, t [mm]	Yield stress, σ_{ys} [MPa]	Ultimate tensile strength, σ_{UTS} [MPa]	Elongation at fracture, A_{80} [%]
CP1200	1.6	1041	1218	6.0
PHS1500	1.5	1075	1552	5.2
DP1000	1.4	738	1027	10.3
TBF	1.5	725	1019	14.7
PHS1000	1.5	988	1007	7.3
Q&P	1.4	909	1209	7.4
CP1000	1.4	908	1002	8.1
TBF/Q&P	1.4	876	1026	11.3



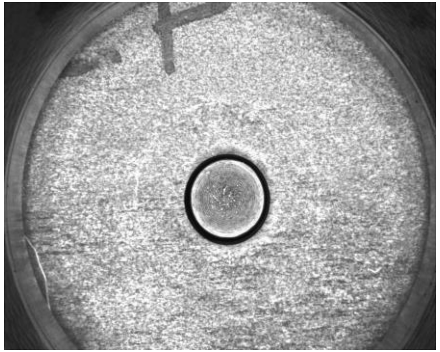
2. Materials and experimental procedures

Experimental procedures: Local ductility

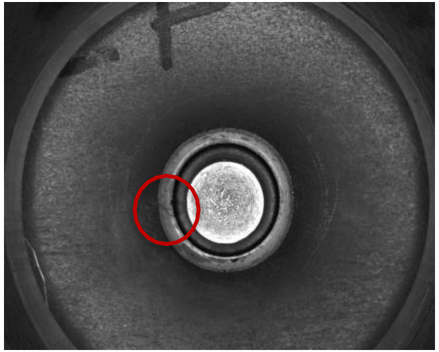
Hole Expansion tests (HET)

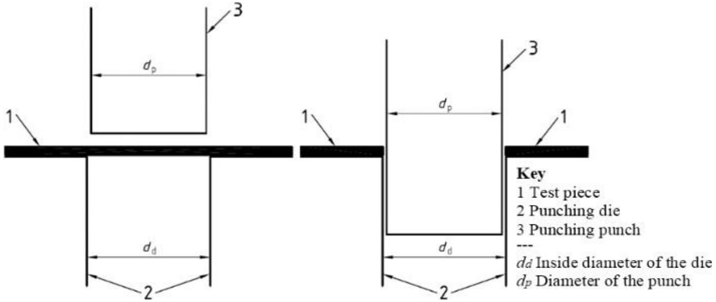


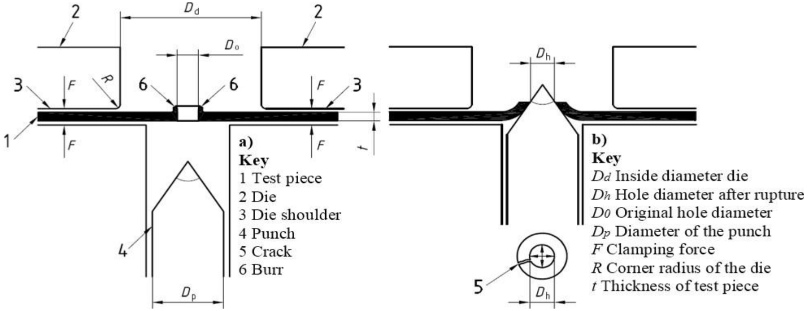
Initial hole diameter D_0=10 mm



First through-thickness crack (Dh)







Clearance= 12 %
Punch speed= 1 mm/s

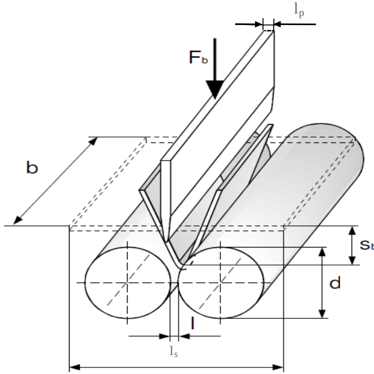
$$HER = \left[\frac{d_h - d_0}{d_0}\right] x100$$

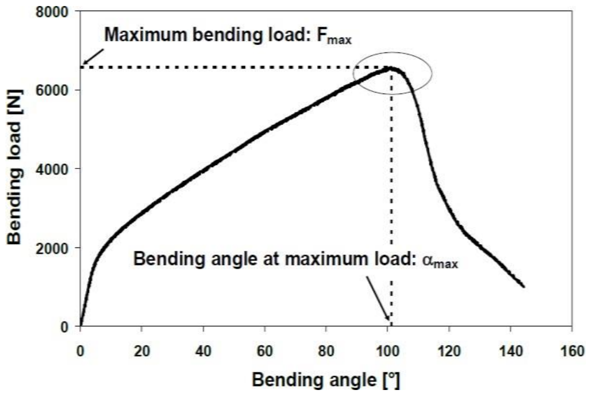
2. Materials and experimental procedures

Experimental procedures: Local ductility

Bendability: V-bending tests (VDA 238-100)

Tests performed at voestalpine Stahl facilities





Fracture criterion

First visible crack

↓

Critical bending angle: α_{crit}

Testing parameters:

- Punch radius: 0.4 mm
- Test speed: 20 mm/min
- Rollers radius: 15 mm
- Free space between rolls: $2t+0.5$

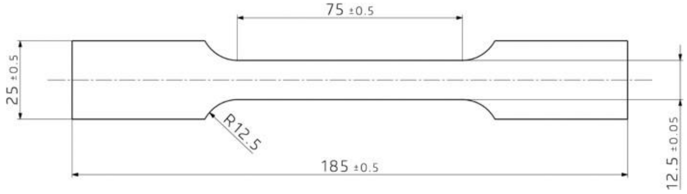
- Bending sample: 60 x 60 mm
- Bending line parallel to the RD
- Test stopped at maximum punch stroke ≈ 160°

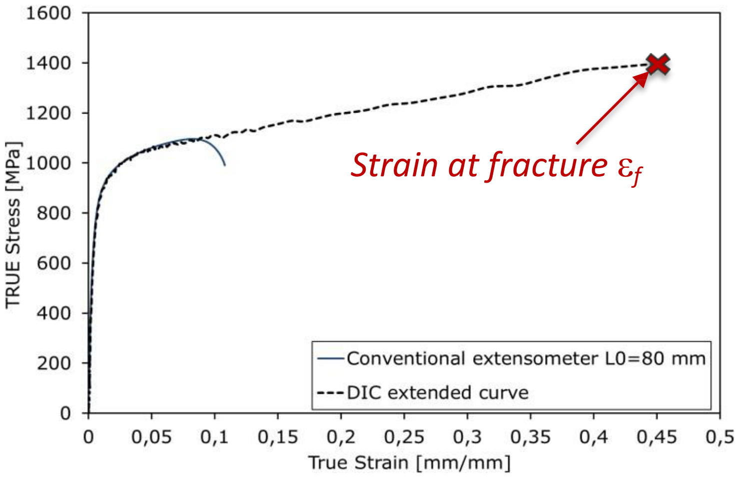
2. Materials and experimental procedures

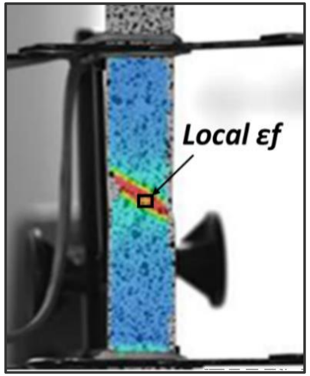
Experimental procedures: Local ductility

Local strain at fracture from uniaxial tensile tests

UNE-EN ISO 6892-1







Testing conditions:

- Test speed 1 (Elastic Zone): 6 Mpa/s
- Test speed 2 (After Yielding): 0,0067 s-1

DIC parameters:

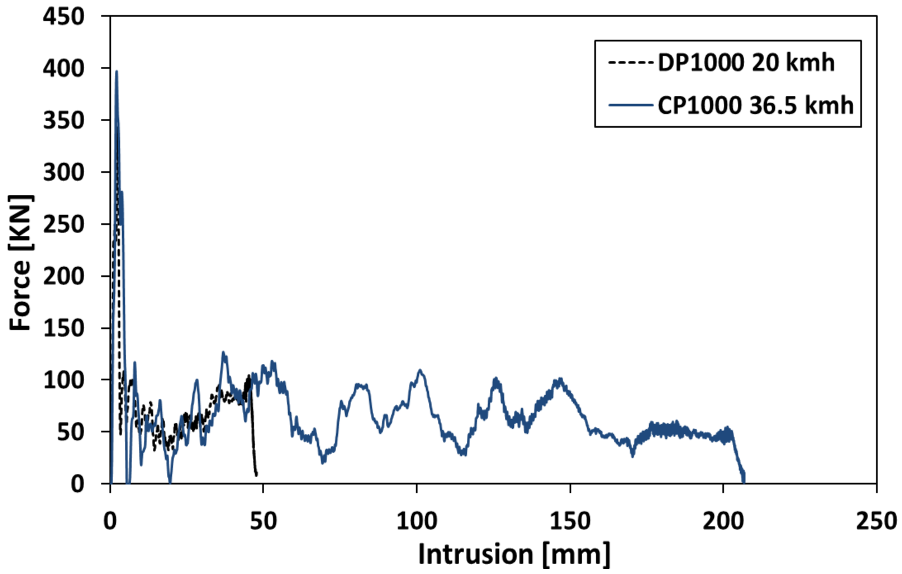
- Facet size: 11 pixels
- Step size: 9 pixels
- Image acquisition: 5 frames/sec

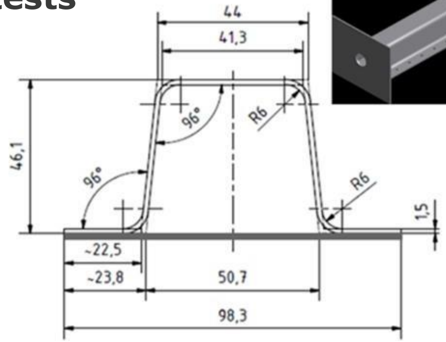
2. Materials and experimental procedures

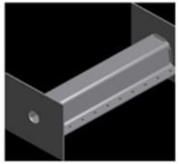
Experimental procedures: Local ductility

Crash resistance: Energy absorbed in axial impact tests

Axial impact tests



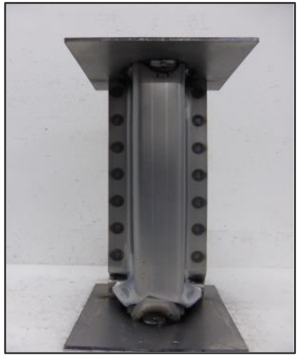




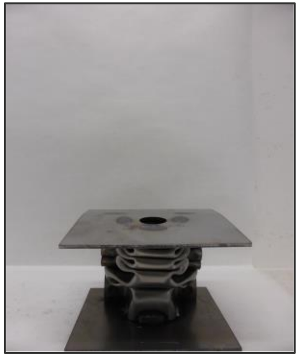
Energy absorbed at maximum intrusion

Normalized by the cross section area

DP1000 20 km/h



CP1000 36.5 km/h



2. Materials and experimental procedures

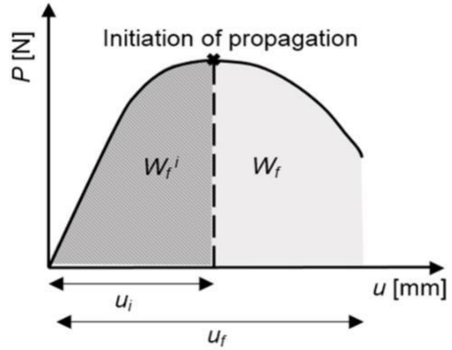
Experimental procedures: Fracture toughness

Essential Work of Fracture

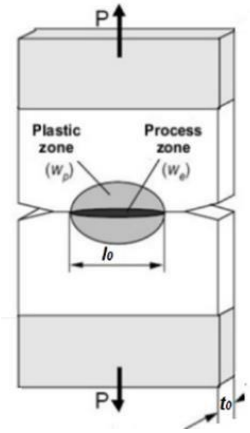
Test conditions

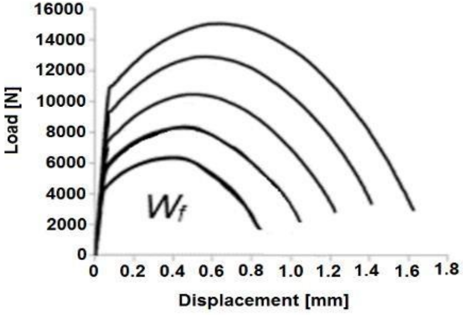
- Ligament lengths: 6-16 mm
- Initial calibrated length: 50 mm
- Test speed: 1 mm/min

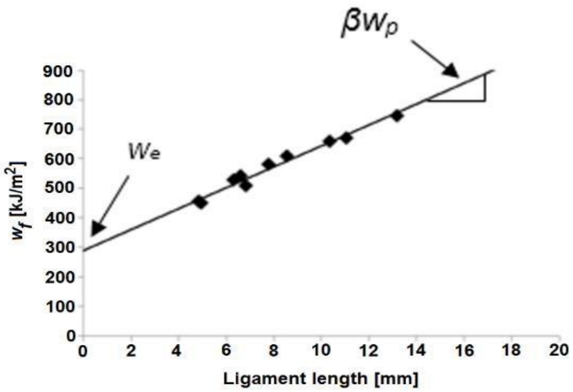
w_e^i: crack initiation resistance

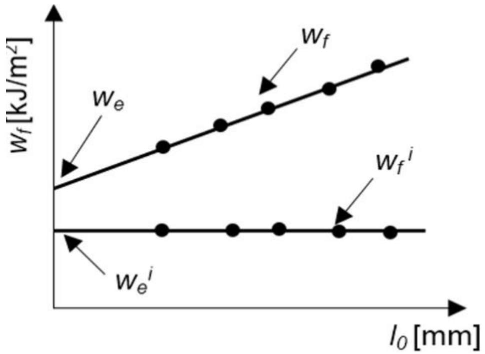


w_e: crack propagation resistance → **Equivalent to J_C**









2. Materials and experimental procedures

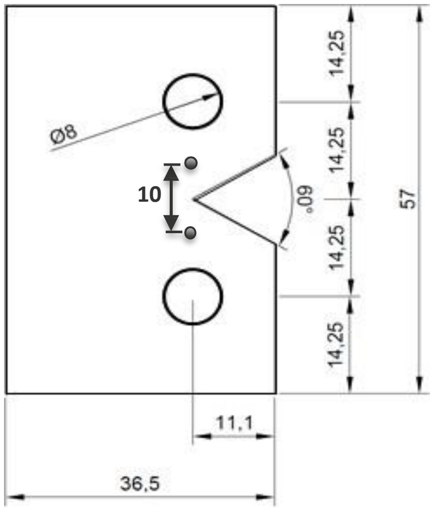
Experimental procedures: Fracture toughness

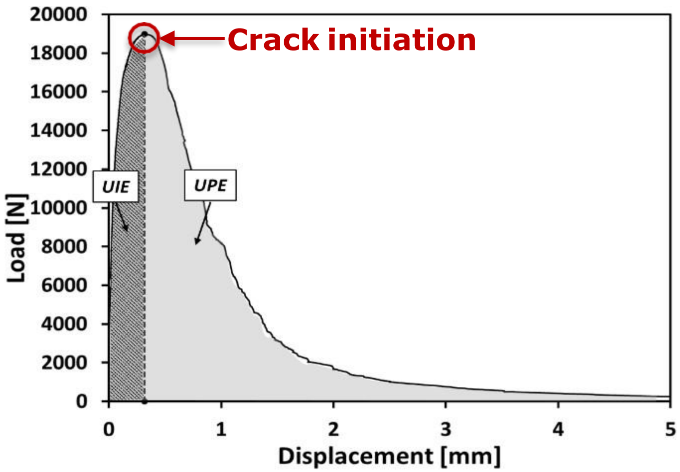
Kahn Tear Tests (ASTM B871)

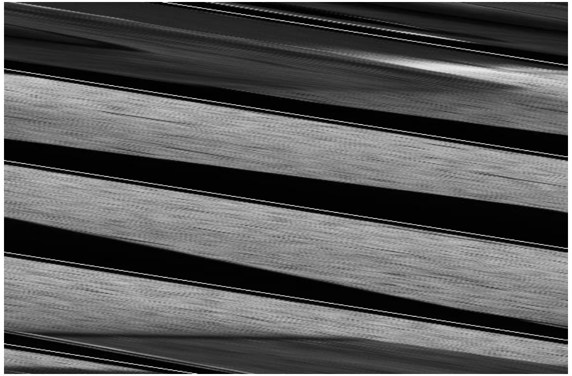
Test conditions
- Initial gauge length: 10 mm
- Test speed: 1 mm/min
- Notch radius: ρ= 150 μm

$$UIE = \frac{\int_0^{\delta_i} P \cdot d\partial}{b*}$$

$$UPE = \frac{\int_{\partial_i}^{\delta_f} P \cdot d\partial}{b*}$$







3.Results and discussion

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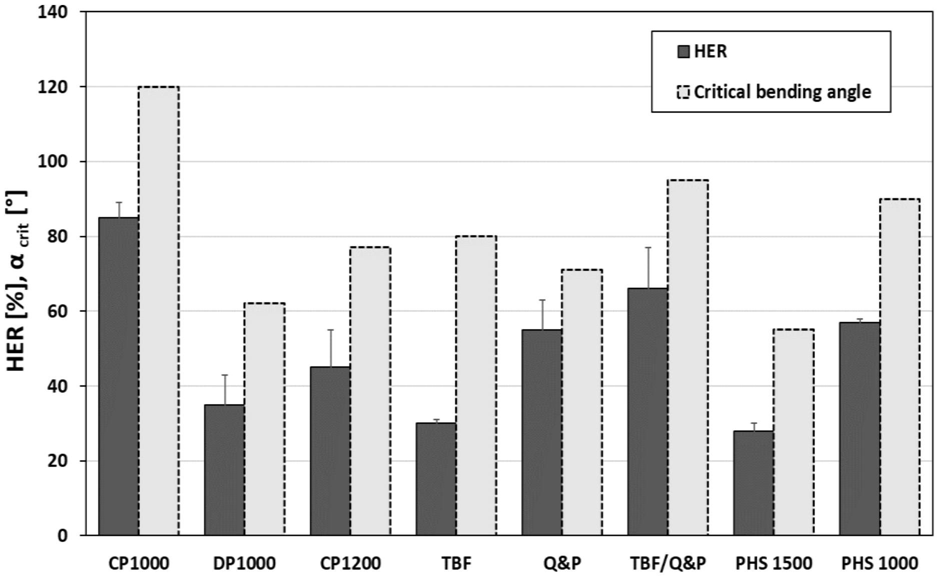
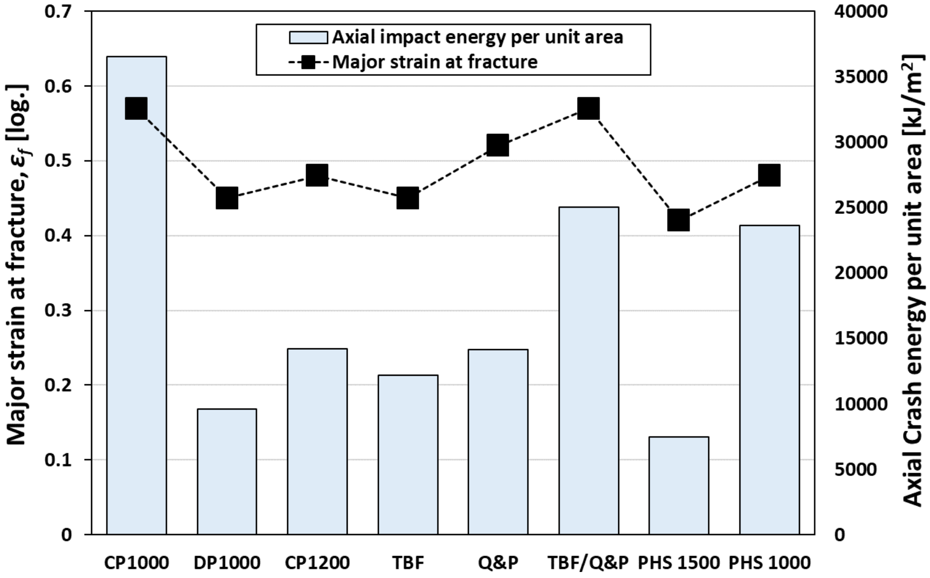
Local ductility



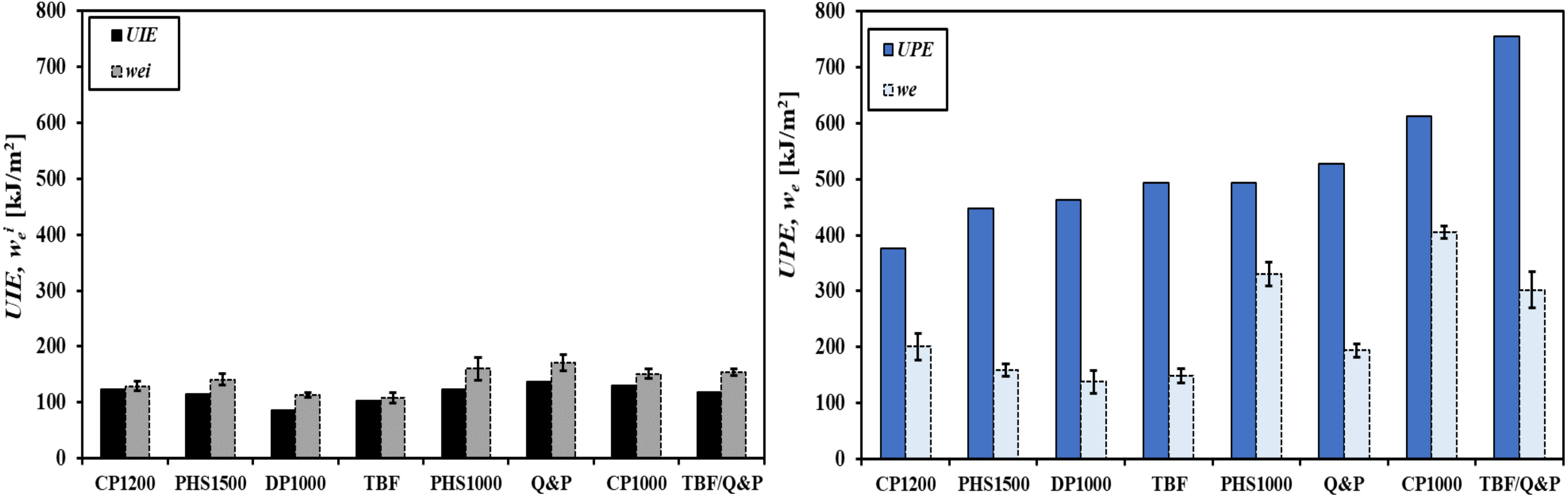


3. Results and discussion

Fracture toughness

w_e^i, *UIE*: Crack initiation resistance

w_e, *UPE*: Crack propagation resistance

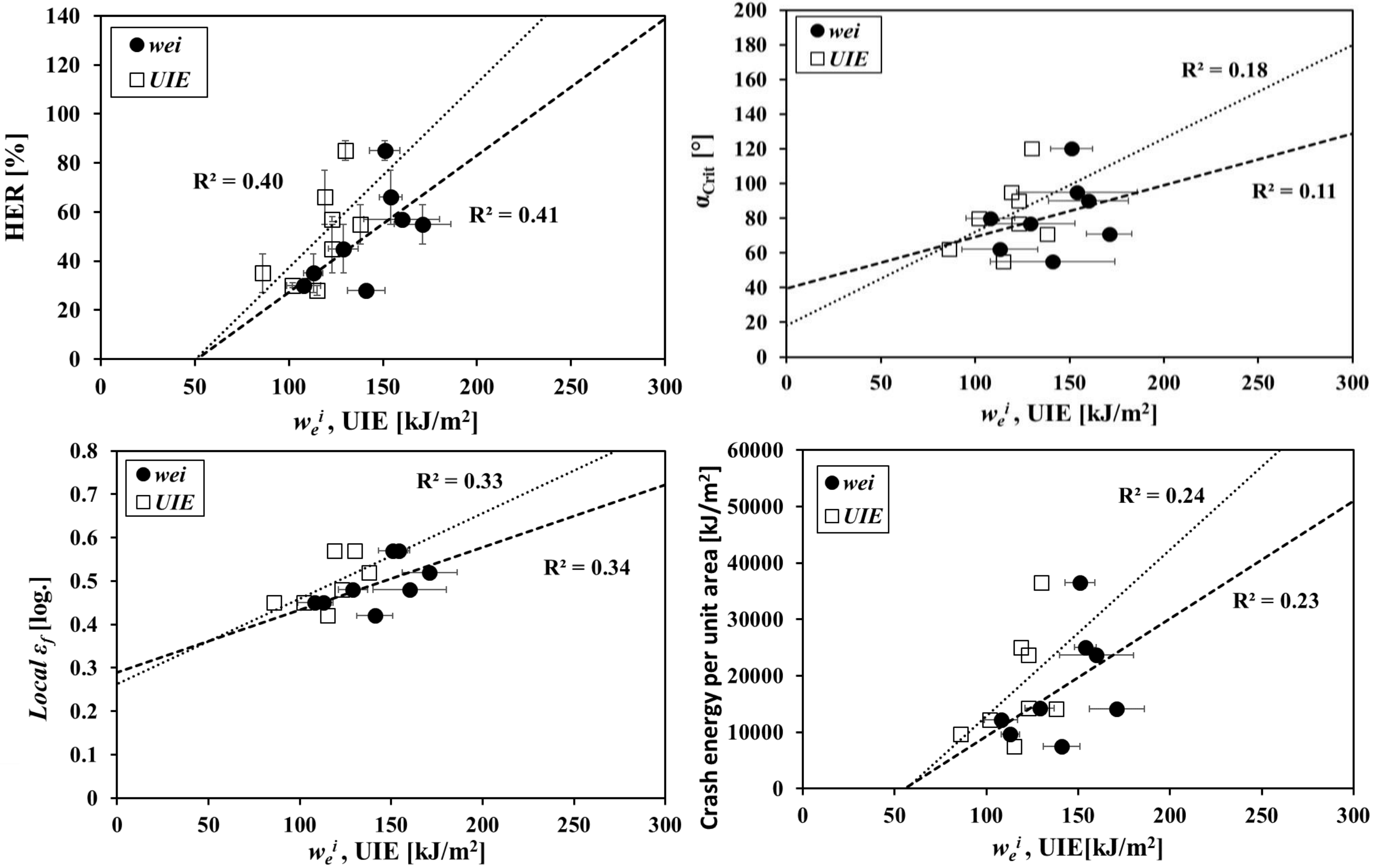


3. Results and discussion

Fracture toughness at cracking initiation

vs

Local ductility

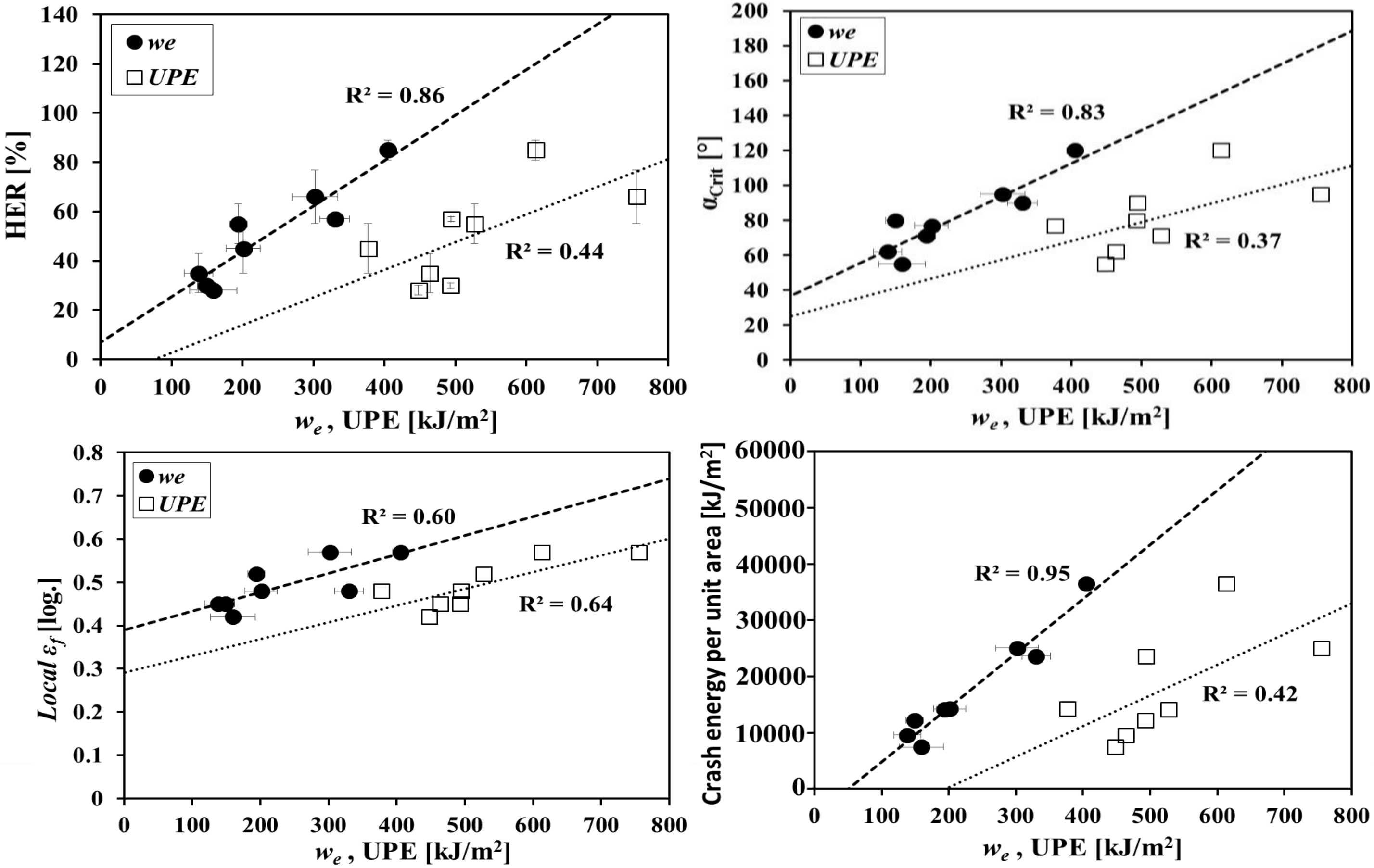


3. Results and discussion

Overall fracture toughness

vs

Local ductility



4. Conclusions

4. Conclusions

- **Good correlation** between **essential work of fracture** and **local ductility.** Steels with **higher fracture toughness** show **greater local ductility and crash energy absorption**
- **Fracture toughness at cracking initiation** (w_{e}, *UIE*) may **undervalue the fracture resistance** and it is not a suitable parameter to predict cracking related phenomena in AHSS.
- **Kahn Tear Tests** are useful to evaluate **crack initiation resistance**. However, they overestimate the crack propagation resistance and are not reliable to evaluate the overall fracture toughness.
- **Fracture toughness** is a suitable material property to predict and understand local ductility and cracking behaviour in AHSS.

5. Further work

-Other materials: Al alloys, Stainless steels, other steels for other sectors, etc.

FORM PLANET

H2020 project: Sheet Metal Forming Testing Hub

FormPlanet project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 814517.

3 years duration, from 2019 to 2021

17 participants from **9 different countries**

8 industrial companies in the **sheet metal forming industry** value chain as early users and validators

User-driven **Integrated Test Bed** offering **unique Testing Methodologies and Modelling approaches** to assure zero-defects production and optimize sheet material development, production and performance.

5 technology providers

eurecat, Fraunhofer IWU, Luleå Tekniska Universitet, Università di Pisa, COMTES FHT

4 service providers

GRANTA Material Intelligence, Applus+, UNE Normalización Española, Letomec srl

8 industrial companies

ArcelorMittal, CRF Centro Ricerche Fiat, arçelik, Lamera, aludium, arania, estamp, APT Automation · Presses · Tooling

5. Further work

FormPlanet calendar

2019

New Testing Methodologies & Technology Services Offer Development

2020

Internal Validation with Industrial Partners

2021

Open Call

For further information please contact:

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Fins a 31/12/2019

Thank You!

david.frometa@eurecat.org

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