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New tool to evaluate the fracture resistance of thin high strength metal sheets

D.Frómeta[1], A.Lara[1], S. Parareda[1], L.Grifé[1] and D.Casellas[1,2]

[1] *Eurecat, Centre Tecnològic de Catalunya, Unit of Metallic and Ceramic Materials, Manresa 08243 (Spain)*
[2] *Division of Mechanics of Solid Materials Luleå University of Technology, 971 87 Luleå (Sweden)*

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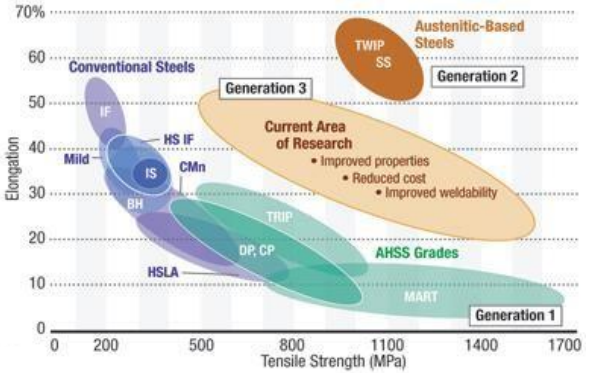
Outline

1. Introduction
2. Background
3. Fracture toughness evaluation of thin ductile sheets
4. New tool to prepare sheet metal specimens for fracture toughness characterization
5. Results and applications
6. Conclusions and further work

1. Introduction

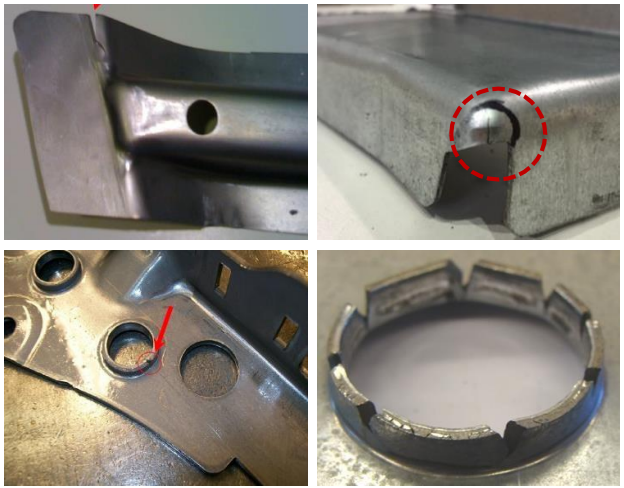
1. Introduction

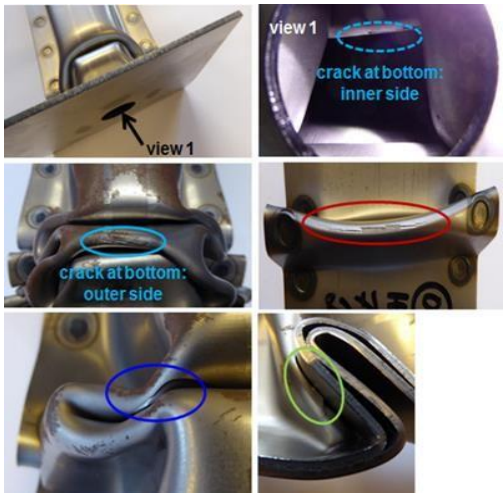
LIGHTWEIGHT AUTOMOTIVE DESIGNS → High strength sheet materials



- HIGH STRENGTH
- GREAT ENERGY ABSORPTION
- GREAT LIGHTWEIGHT POTENTIAL

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

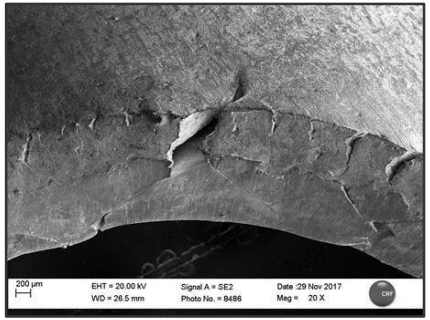


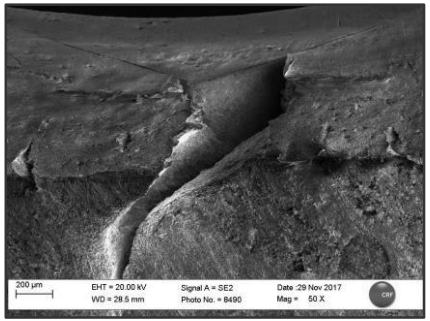


1. Introduction

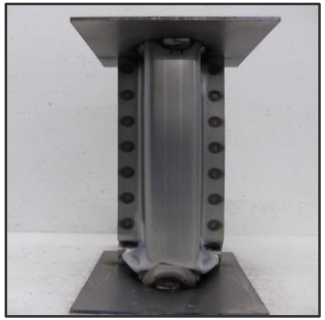
Cracking related fractures → **Crack initiation and propagation resistance** → **Fracture toughness**

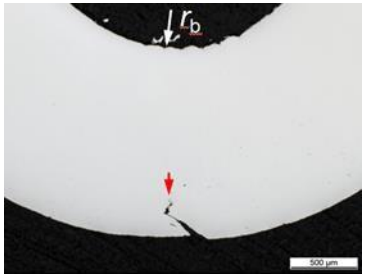
Edge cracking resistance

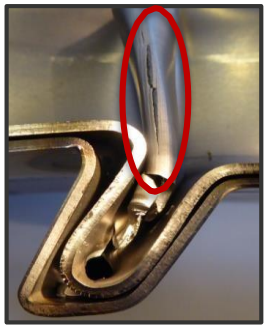


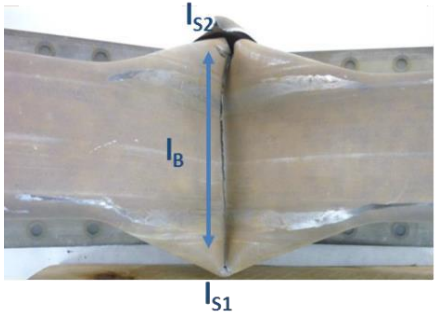


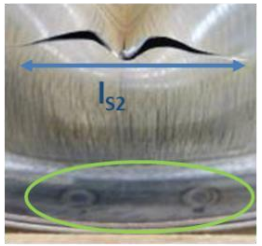
Crash failure behaviour









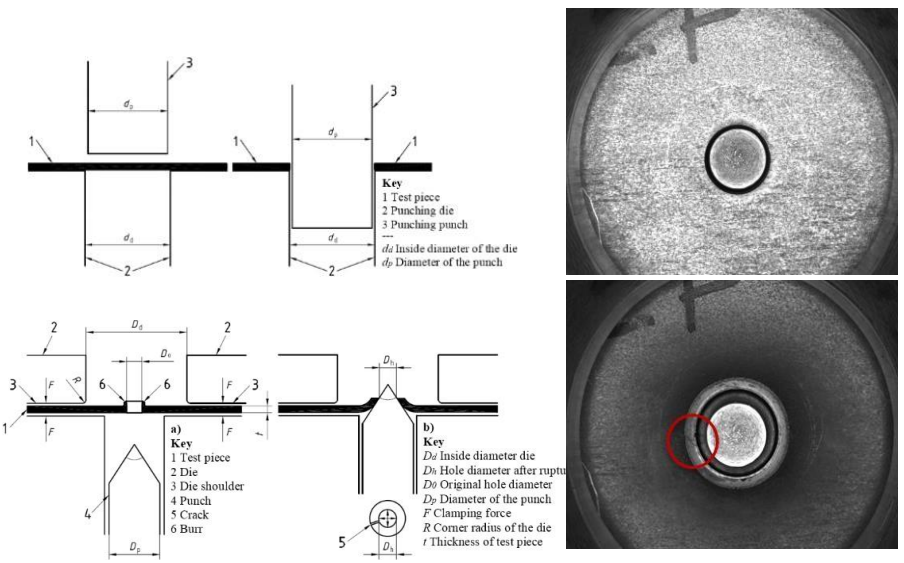


2.Background

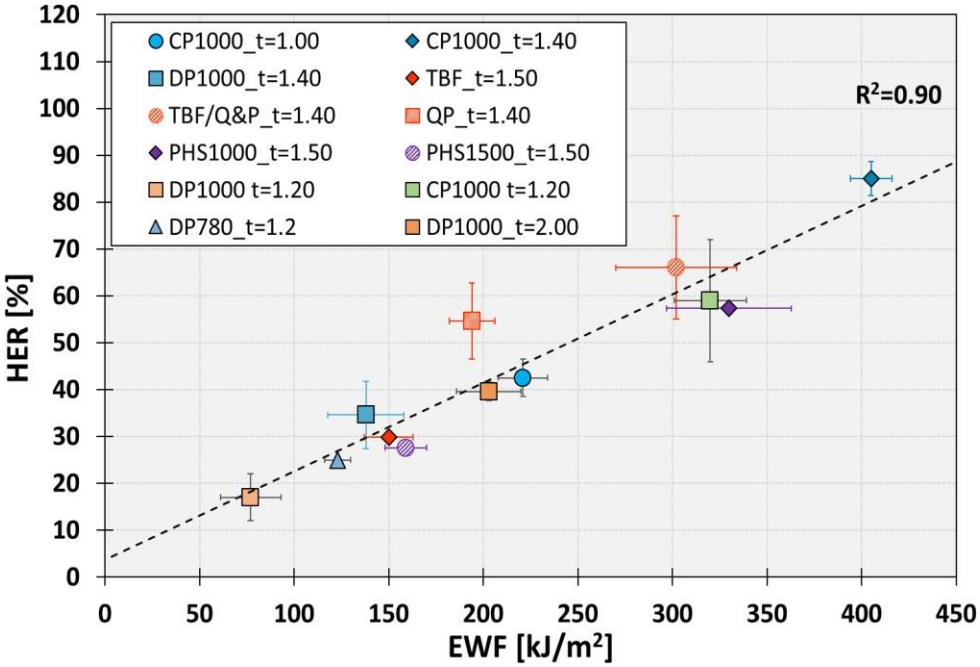
2. Background

Fracture toughness to understand crack-related problems in AHSS: Stretch flangeability

Hole Expansion Test: ISO 16630



Correlation fracture toughness-HER



Hole Expansion Ratio

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

2. Background

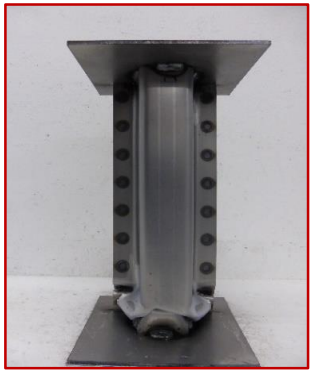
Fracture toughness to understand crack-related problems in AHSS: Crash behaviour

Low fracture toughness

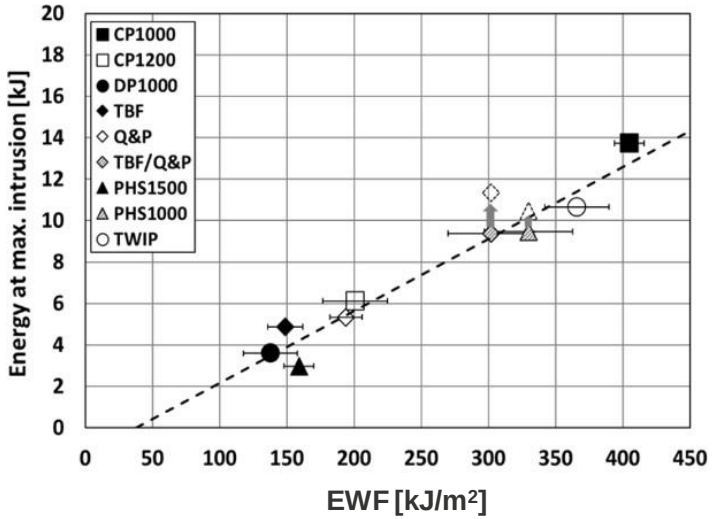
- Rapid crack propagation
- Poor crash foldability
- Low crash performance

High fracture toughness

- Small crack propagation
- High crash foldability
- High crash performance



Correlation fracture toughness-crash resistance



Frómeta D, Lara A, Molas S, Casellas D, Rehrl J, Suppan C, Larour P and Calvo J. On the correlation between fracture toughness and crash resistance of advanced high strength steels. Eng. Frac. Mech. 205 (2019) 319-332

3. Fracture toughness evaluation of thin ductile sheets

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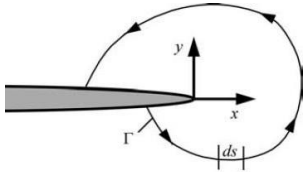
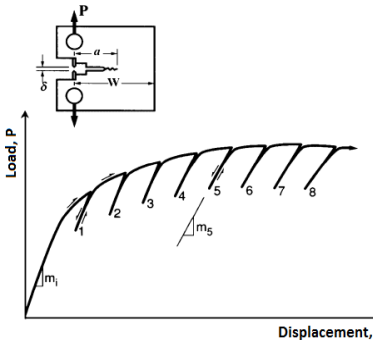
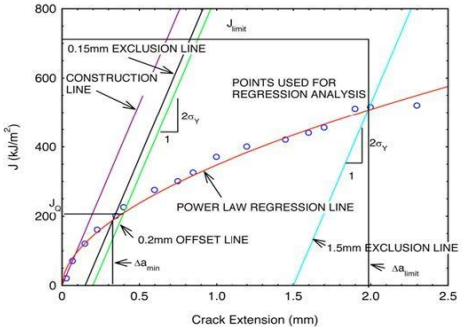
Elastic Plastic Fracture Mechanics (EPFM)

J-Integral (ASTM E1820)

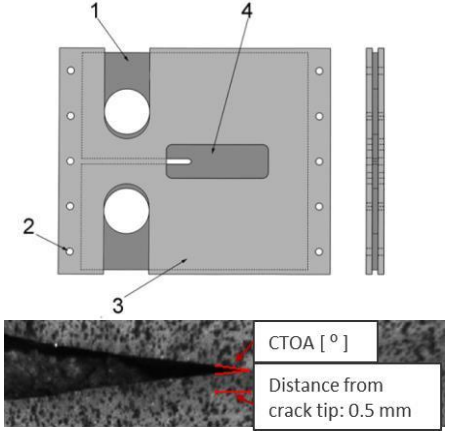


$$J = \int_{\Gamma} \left(w dy - T_i \frac{\partial u_i}{\partial x} ds \right)$$

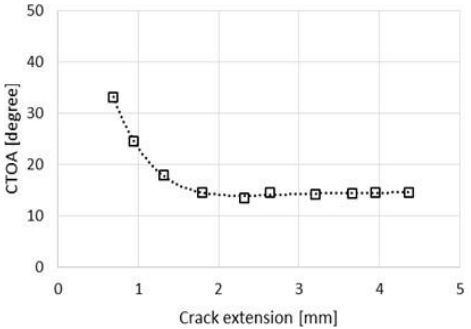




Crack Tip Opening Angle, CTOA (ASTM E2472)



1 C(T) specimen
2 bolt holes
3 anti-buckling plates (front and back)
4 crack viewing region



- Complex experimental procedure and specimen preparation
- Crack growth monitoring
- Complex data post-processing
- Special equipment: Fatigue testing equipment, microscope, DIC, etc.

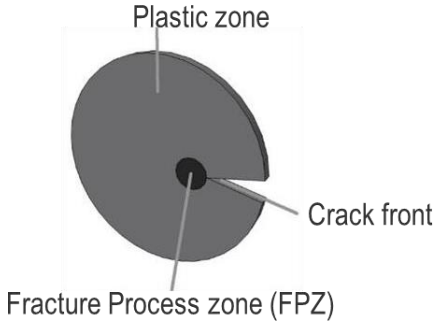
3. Fracture toughness evaluation of thin ductile sheets

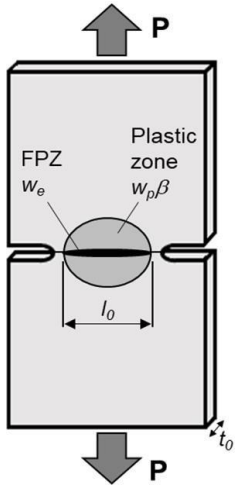
Essential work of fracture (EWF)

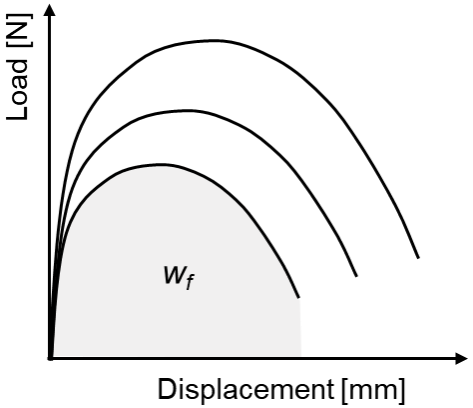
$$W_f = W_e + W_P$$

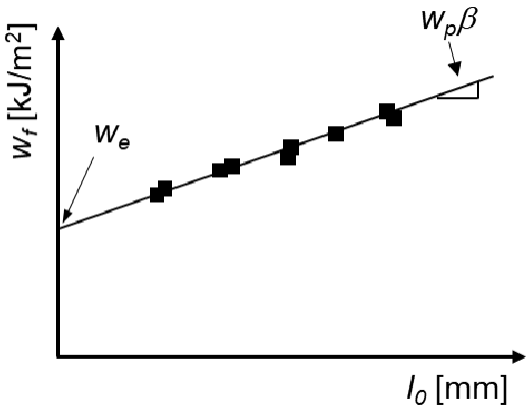
$$W_f = w_e lt + \beta w_p l^2 t$$

$$\frac{W_f}{lt} = w_f = w_e + \beta w_p l$$





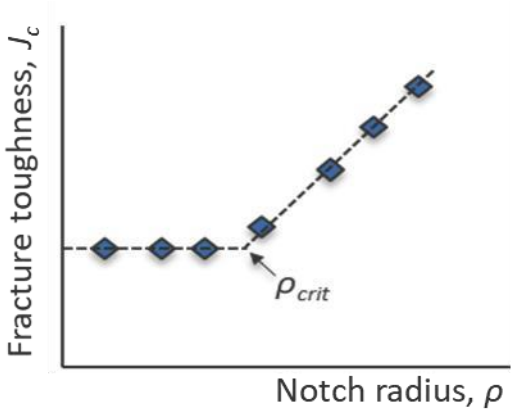


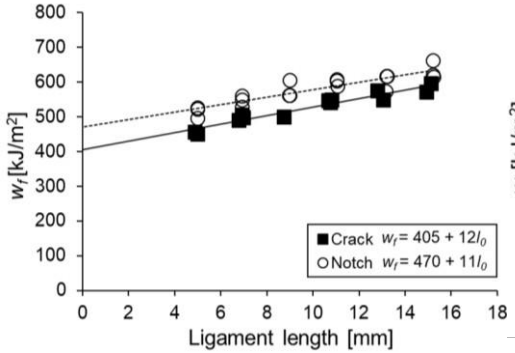


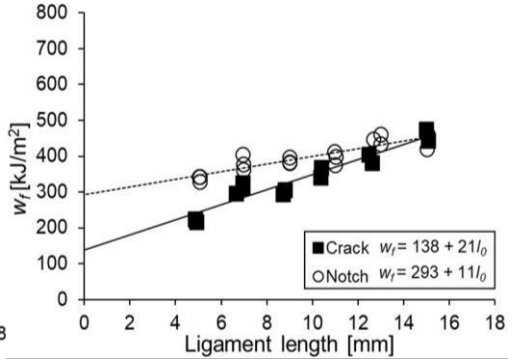
- Simple method
- No crack monitoring
- No complex data post-processing
- Complex specimen preparation: fatigue pre-cracking

3. Fracture toughness evaluation of thin ductile sheets

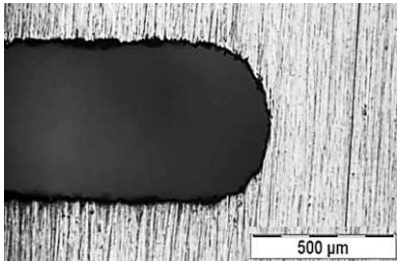
Influence of notch radius



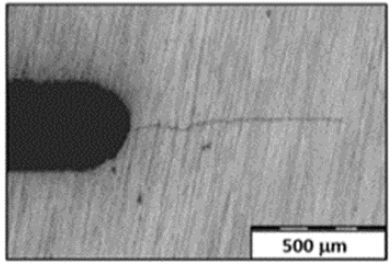


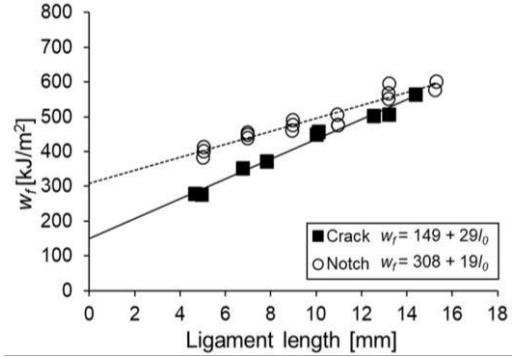


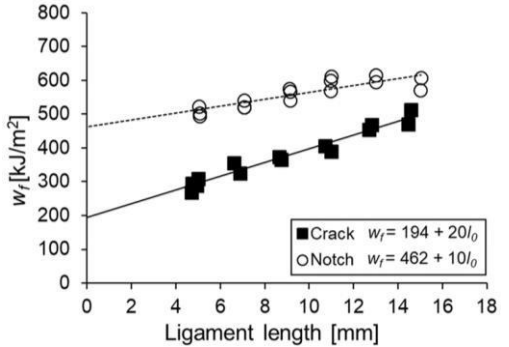
EDM notch (ρ≈150 µm)



Fatigue pre-crack (ρ≈0.1 µm)







4. New tool to prepare sheet metal specimens for fracture toughness characterization

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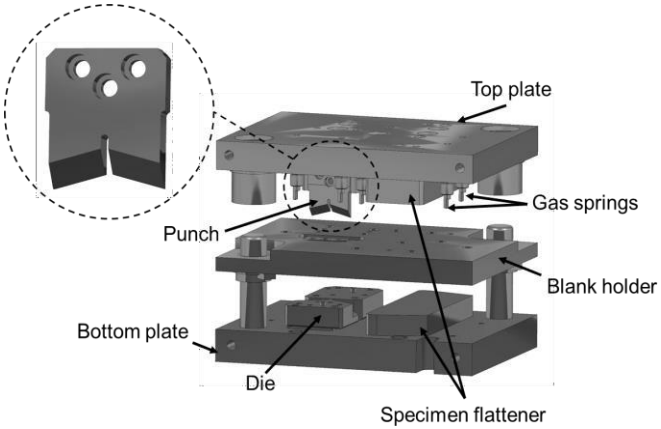
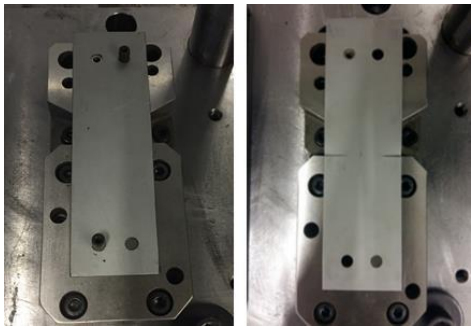
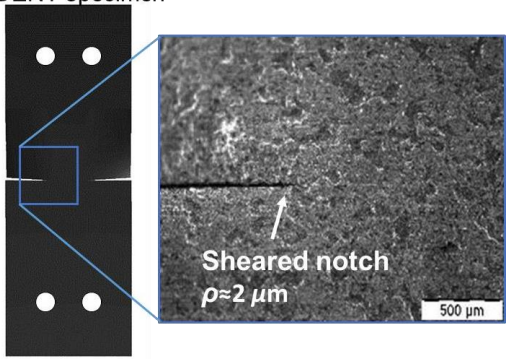
Experimental setup

European Patent EP 3567364A1



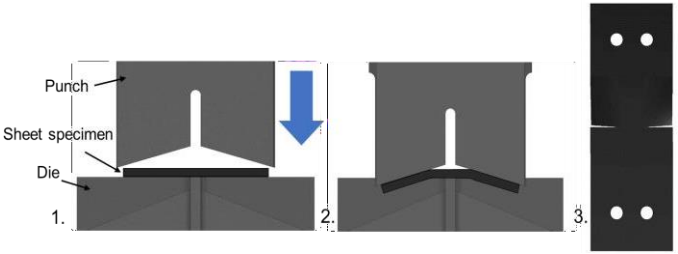


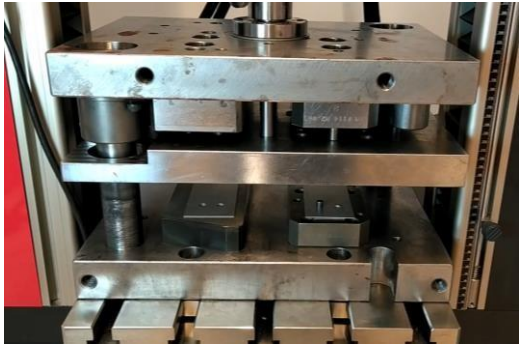
DENT specimen

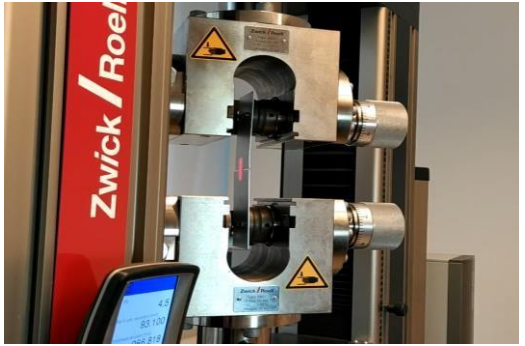


4. New tool to prepare sheet metal specimens for fracture toughness characterization

Experimental procedure







5. Results and applications

5. Results and applications

Materials investigated

- Four AHSS 1000-1200 MPa UTS
- Thickness ≈ 1.4 mm
- One Complex Phase (CP) steel
- Two Dual-Phase (DP) steels
- One 3rd Generation TRIP-assisted steel

Material	Thickness, t [mm]	Yield strength, σ_{ys} [MPa]	Ultimate Tensile Strength, σ_{UTS} [MPa]	Uniform elongation, A_g [%]	Elongation at fracture, A_{80} [%]	Strain hardening exponent, $n_{2-4\%}$
CP	1.4	915	1008	4.8	8.8	0.05
DP-A	1.35	807	1057	6.6	9.6	0.13
DP-B	1.4	769	1040	5.3	8.7	0.09
3rd GEN	1.4	987	1216	9.2	12.6	0.11

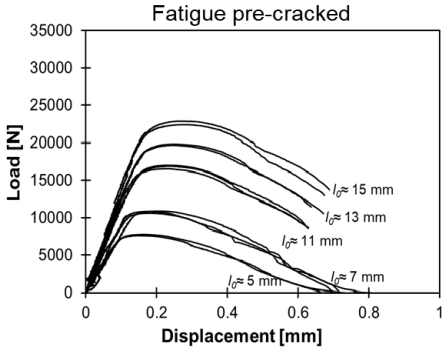
Testing conditions

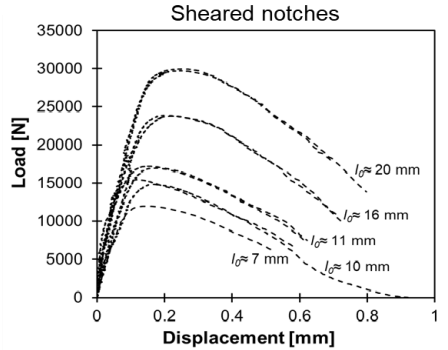
- Two notch conditions: Fatigue pre-cracked specimens and specimens with sheared notches
- Ligament lengths: 5-20 mm
- 8-12 specimens
- Displacement rate: 1 mm/min
- Extensometer marks: 25 mm

5. Results and applications

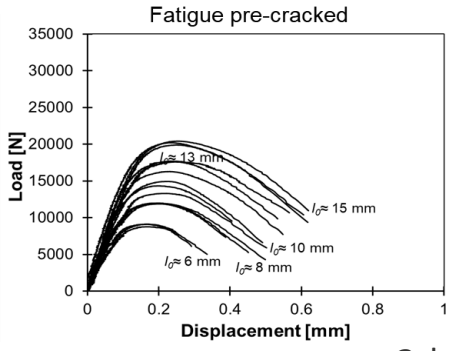
Results

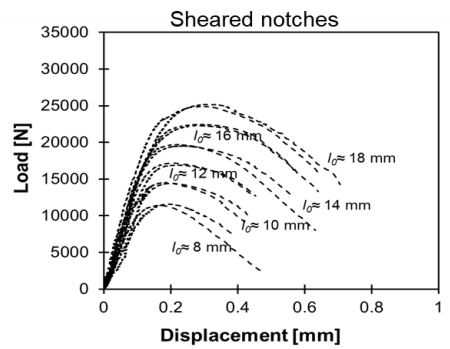
CP



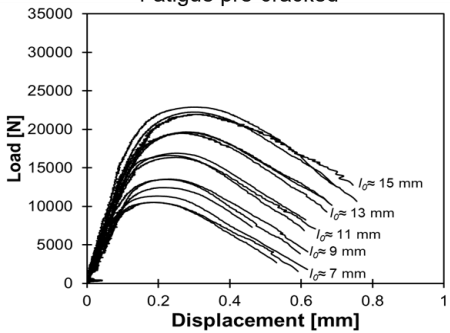


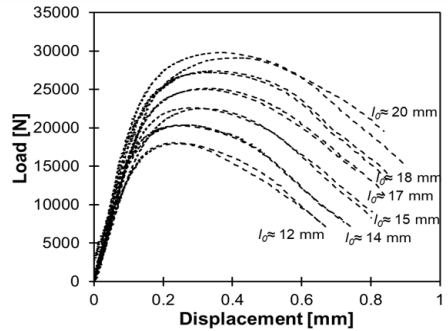
DP-A



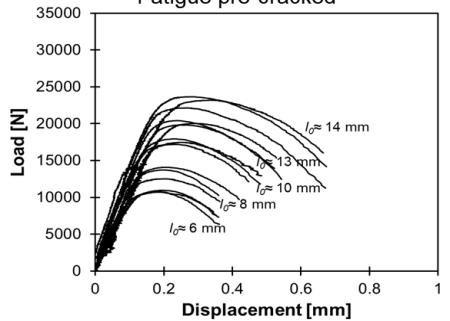


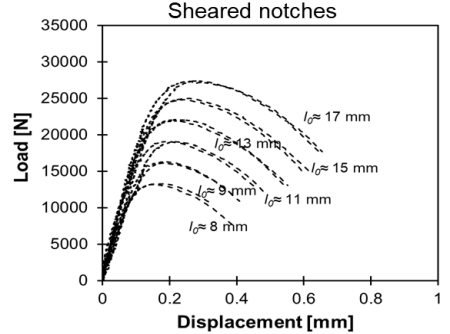
DP-B





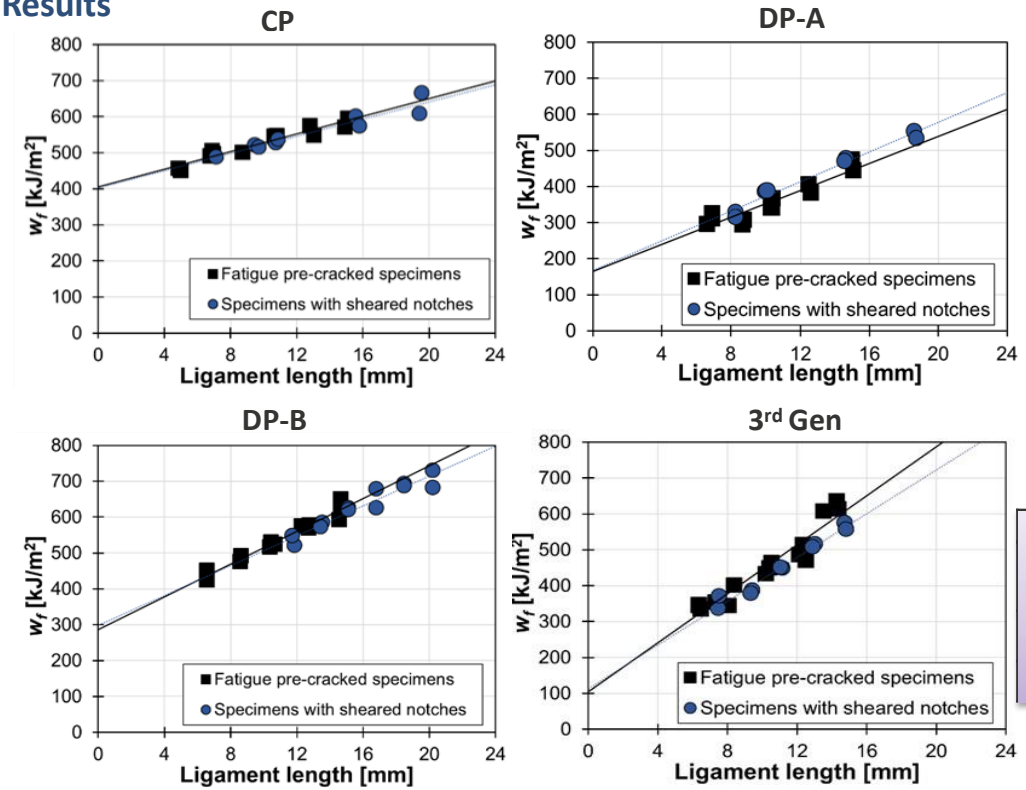
3rd Gen

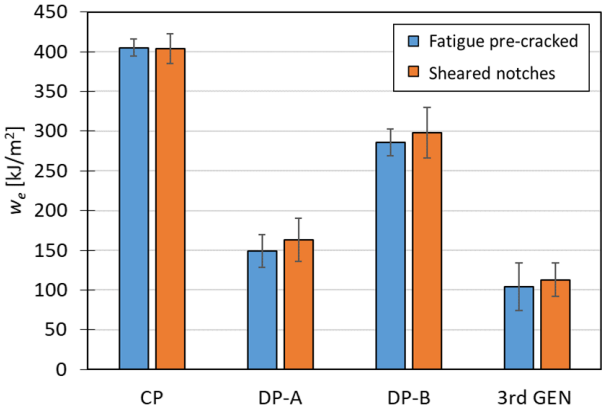




5. Results and applications

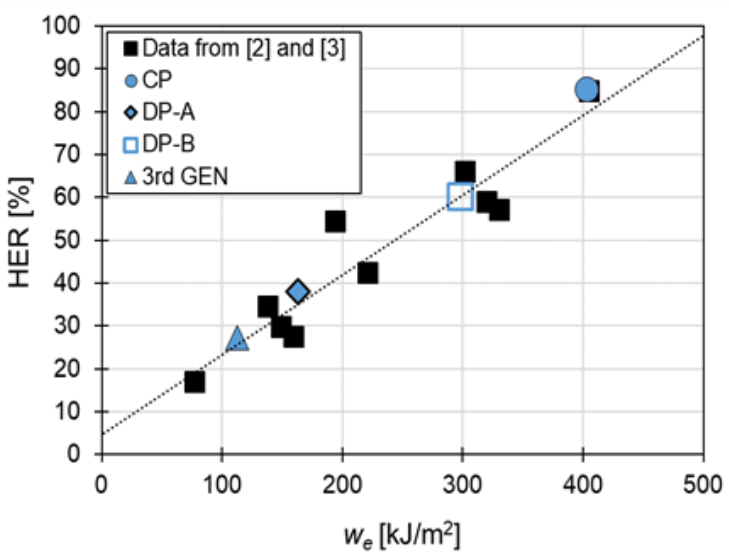
Results





5. Results and applications

Applications: Estimation of cracking behaviour



References

2 Casellas D, Lara A, Frómeta D, Gutiérrez D, Molas S, Pérez Ll , Rehrl J, Suppan C. Fracture Toughness to Understand Stretch-Flangeability and Edge Cracking Resistance in AHSS. Metall. and Mat. Trans. A 48 (2017) 86-94.

3Frómeta D, Lara A, Pararedа S, Casellas D. Evaluation of Edge Formability in High Strength Sheets Through a Fracture Mechanics Approach. AIP Conference Proceedings 2113, 160007 (2019).

6. Conclusions and further work

6. Conclusions and further work

Conclusions

- The new tool has shown to be **suitable to easily prepare notched specimens** for fracture toughness characterization of high strength metal sheets
- The tool can be **easily mounted in a universal testing machine. The notching process is fast and simple**
- The values of **EWF** obtained from specimens with **sheared notches** are **equivalent** to those obtained with **fatigue pre-cracked specimens**
- The notching procedure is a **fast and cost-effective alternative** to conventional fatigue pre-cracking operations. It **can save up to 99% of the time** in specimens preparation**.**
- The obtained **toughness** values are suitable to **estimate the cracking resistance** of high strength steel sheets

6. Conclusions and further work

Further work

- Applicability to other materials and thicknesses: Al alloys, stainless steels, polymers, composites
- Effect of cutting clearance, punch wear, etc. on notch quality. Influence on toughness results
- Process standardization
- Industrial scale trials

H2020 project: Sheet Metal Forming Testing Hub
https://formplanet.eu/

2021 FormPlanet Test Bed's Open Call 2021

For further information please contact at info@formplanet.eu

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

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Thank You!

david.frometa@eurecat.org