"innovating for business"

eurecat
Centre Tecnològic de Catalunya

tecnio catalonia
ACCIÓ
Generalitat de Catalunya
Fins a 31/12/2019

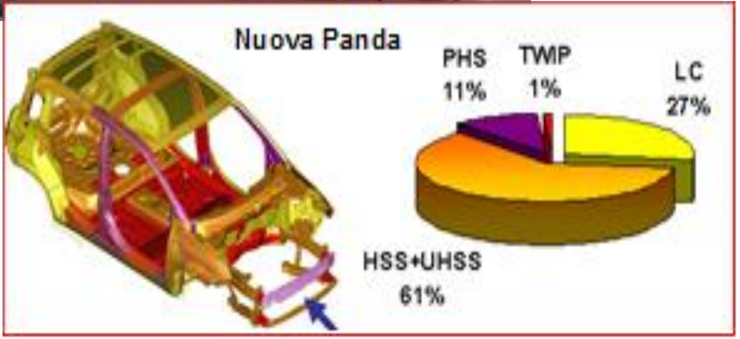
New testing device to evaluate edge cracking resistance and crashworthiness of thin metallic sheets

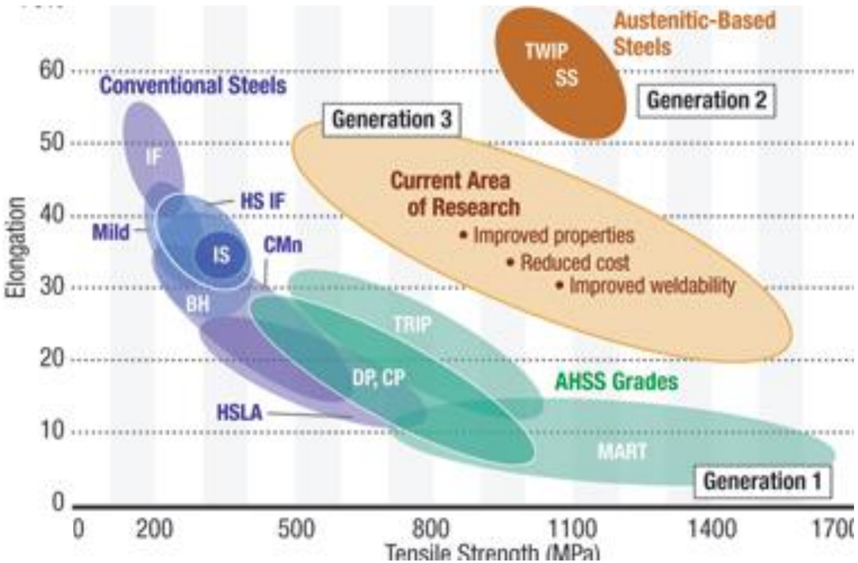
Daniel Casellas, David Frómeta, Antoni Lara, Sergi Parareda

testXpo - 2019
28TH International forum for Material Testing
Ulm, 14-17 October 2019

Motivation: PROBLEM/CHALLENGE

HIGH STRENGTH MATERIALS SHEETS are used for lightweighting (gauge thinning)





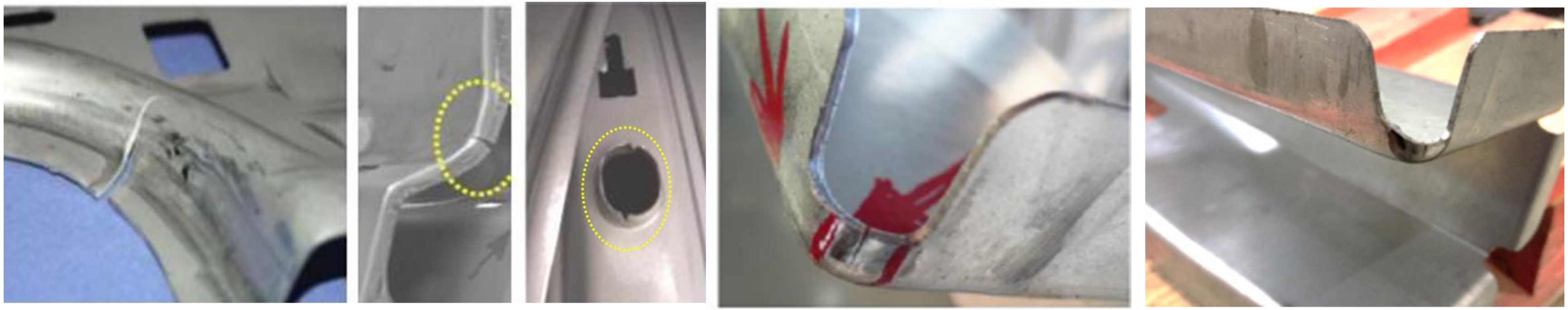
AHSS: Advanced High Strength Steels

Motivation: PROBLEM/CHALLENGE

HIGH STRENGTH MATERIALS SHEETS are used for lightweighting (gauge thinning)

BUT....

NEW MATERIALS BRING NEW PROBLEMS: SHEETS CAN FRACTURE DURING FORMING

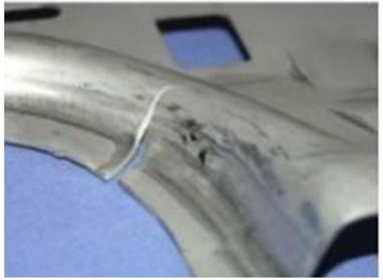
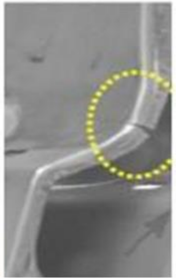


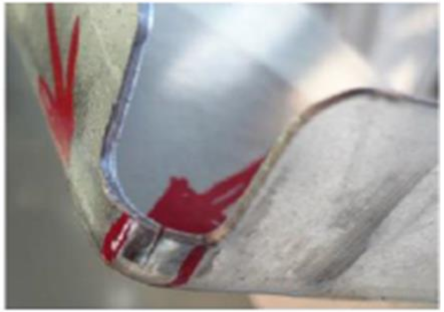
NEW CHALLENGE : DEAL WITH CRACK-RELATED PROBLEMS IN SHEET METAL FORMING

Motivation: NEED

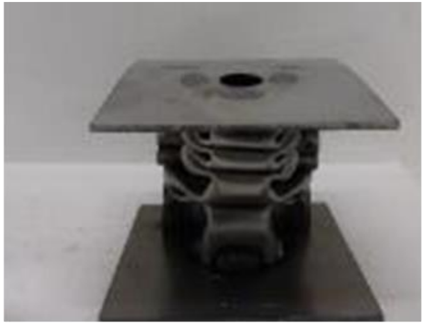
Experimental tools to **predict/estimate cracking** behavior in **HIGH STRENGTH MATERIALS**

PREDICT Edge cracking

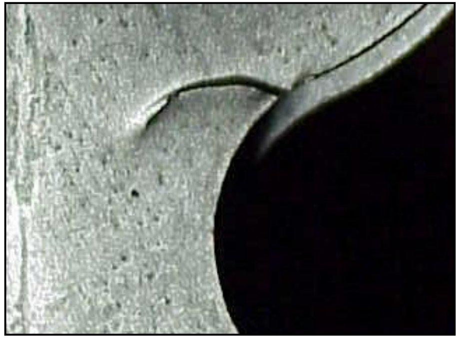






ESTIMATE crashworthiness




Motivation: SOLUTION



Crack-related problems should be addressed considering the material property that controls crack propagation resistance:

FRACTURE TOUGHNESS

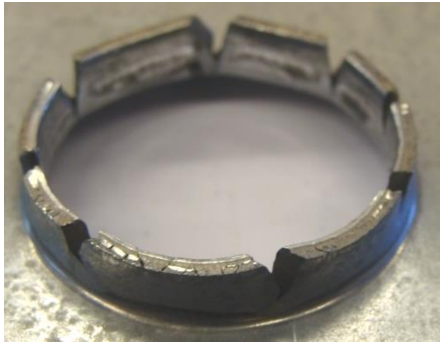
- How to measure fracture toughness in AHSS sheets?

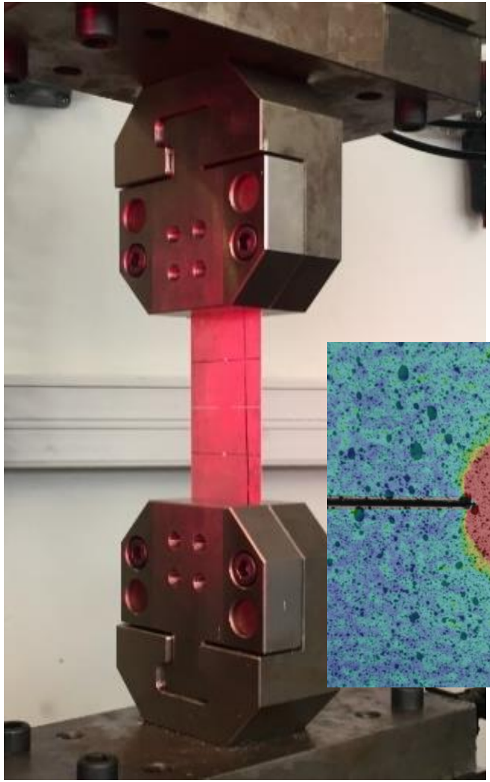
  ✓ *ESSENTIAL WORK OF FRACTURE METHODOLOGY*

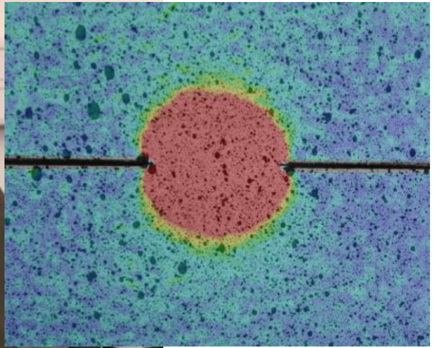
- Can fracture toughness be used to rationalize crack related problems?
  - Edge cracking
  - Crashworthiness

✓ **YES IT CAN BE USED**

Outline

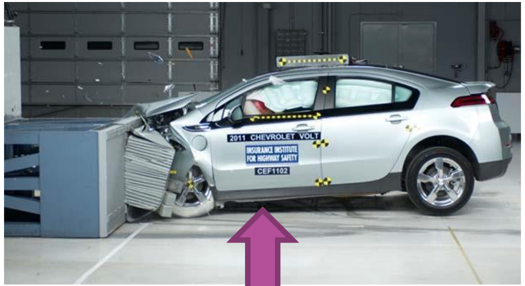






1. BACKGROUND IN CRACK-RELATED PROBLEMS
2. FRACTURE TOUGHNESS EVALUATION IN THIN SHEETS

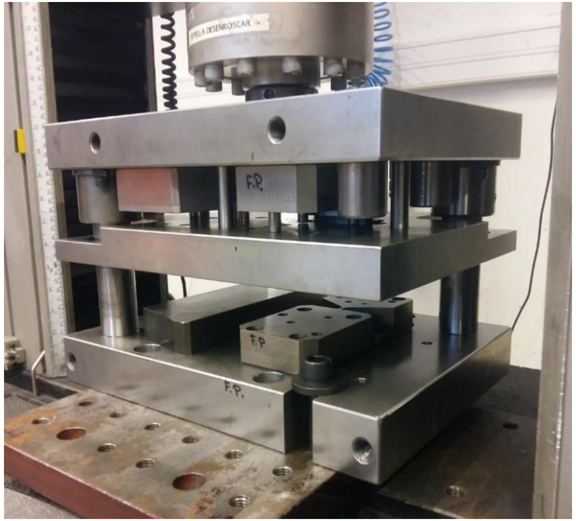
Motivation & Outline

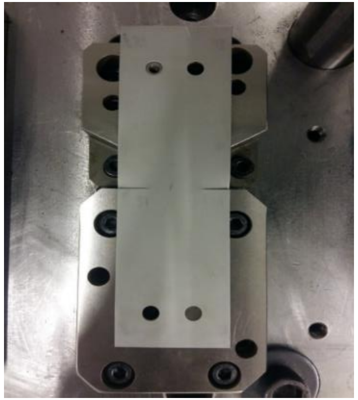


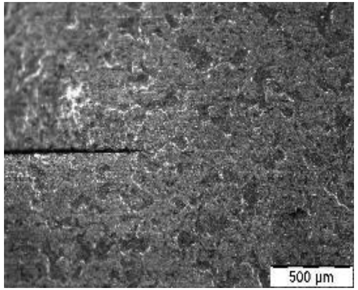
1. BACKGROUND IN CRACK-RELATED PROBLEMS
2. FRACTURE TOUGHNESS EVALUATION IN THIN SHEETS
3. FRACTURE TOUGHNESS AS A MATERIAL PROPERTY

LAB SCALE TESTS ?

Motivation & Outline







1. BACKGROUND IN CRACK-RELATED PROBLEMS
2. FRACTURE TOUGHNESS EVALUATION IN THIN SHEETS
3. FRACTURE TOUGHNESS AS A MATERIAL PROPERTY
4. NEW DEVICE TO MEASURE FRACTURE TOUGHNESS
5. CONCLUSIONS AND FUTURE WORKS

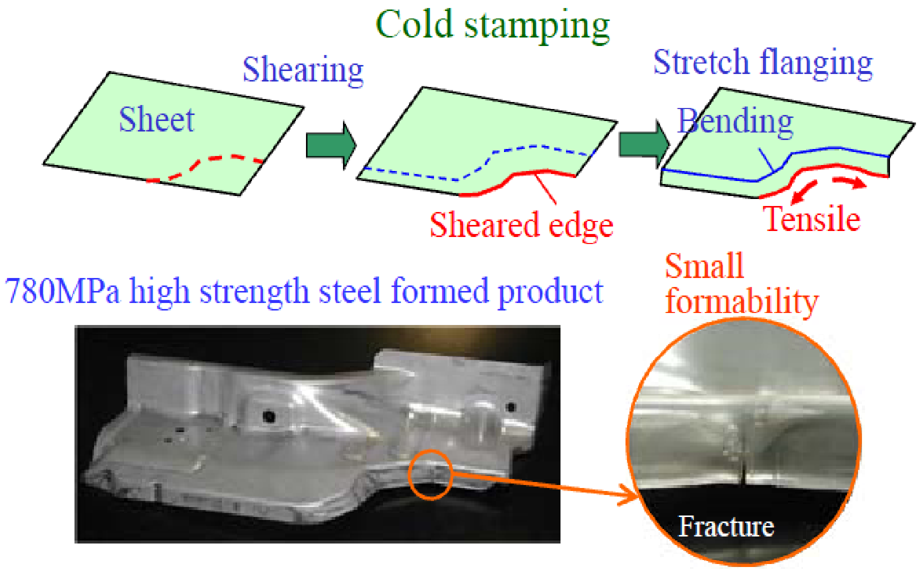
1. Background in crack-related problems

Outline

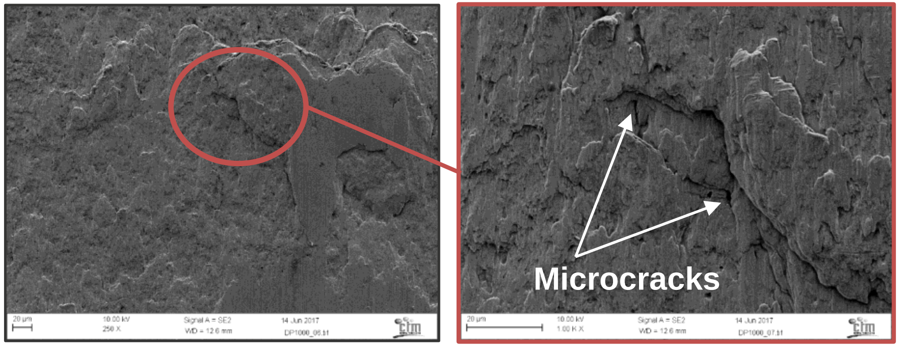
1. Background: crack related problems

- Edge cracking in cold forming

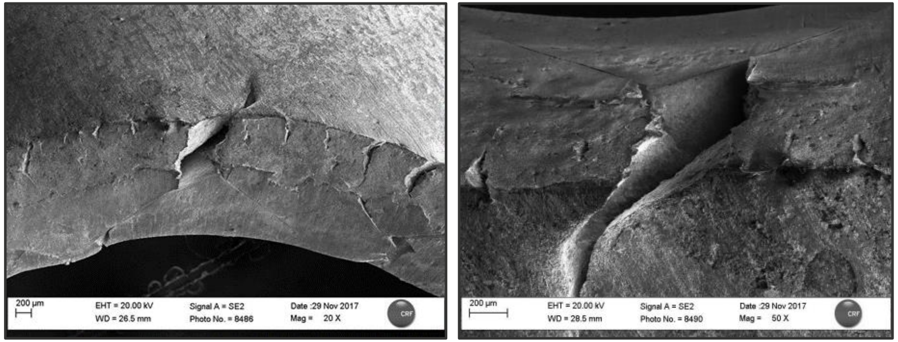
Damage | **Crack propagation**



Damage

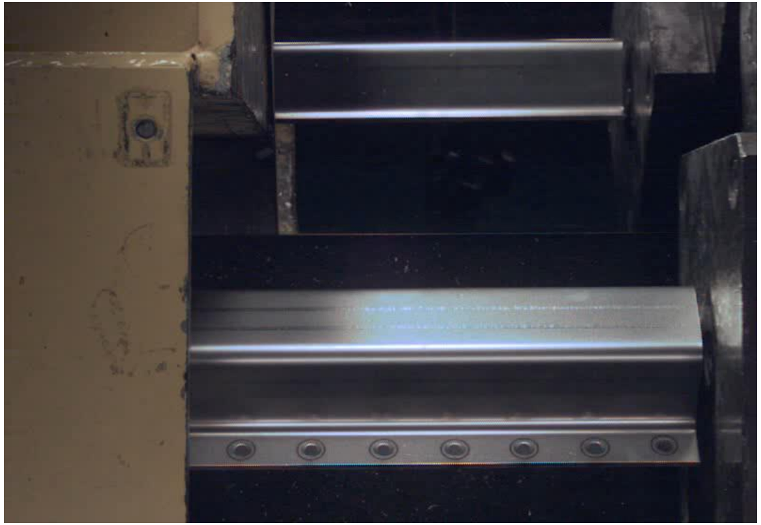


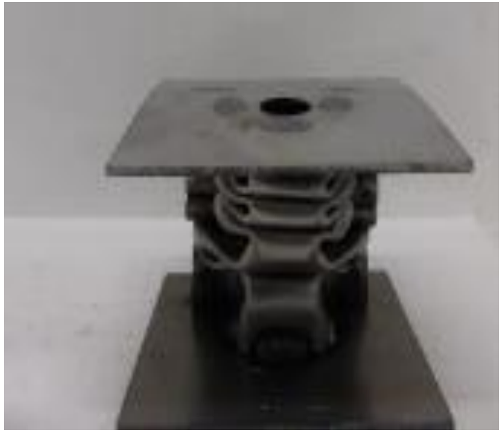
Crack propagation



1. Background: crack related problems

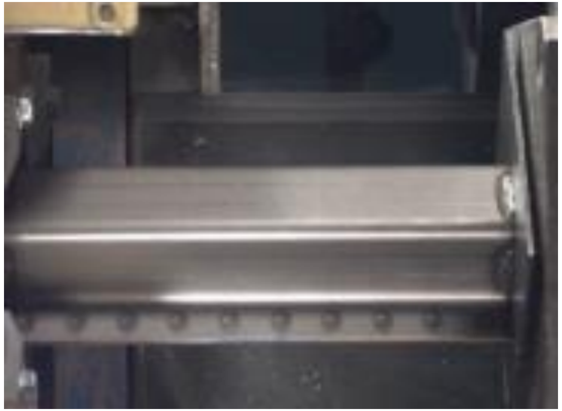
- Crack formation in crash



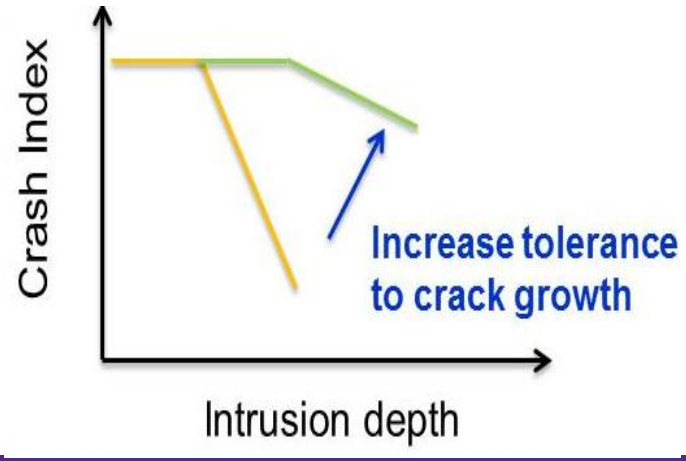


1. Background: crack related problems

- Crack formation in crash

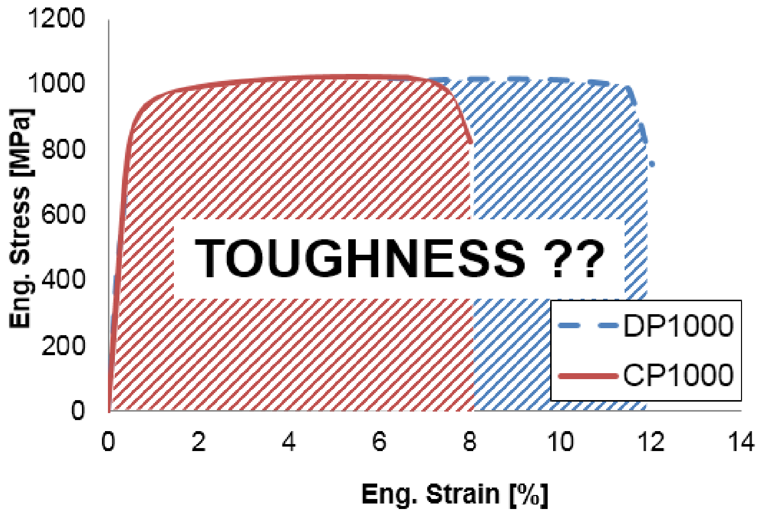


Crash index	Damage
100	no cracks
>75	crack length < 10 mm
50-75	10 mm < crack length < 25 mm
25-50	crack length > 25 mm
<25	"splitting and curling"; multiple breaks



2. Fracture toughness evaluation in thin sheets

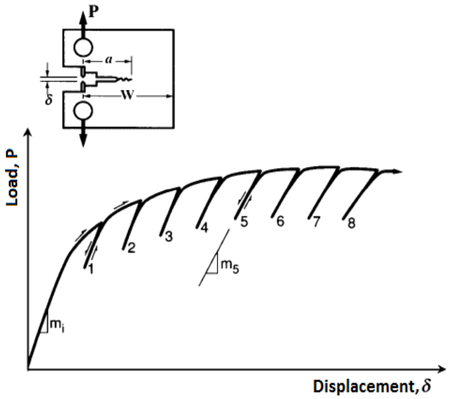
2. Fracture toughness evaluation of thin sheets

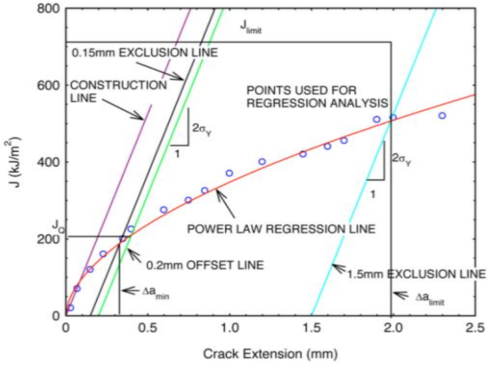


- ✗ Area under stress-strain curve gives no information about crack propagation resistance
- ✗ Linear Elastic Fracture Mechanics (K_{IC}): large plastic zone in metal sheets
- ➢ Elastic-plastic fracture mechanics: J-integral (J_C), CTOD
- ➢ Alternative tests

2. Fracture toughness evaluation of thin sheets

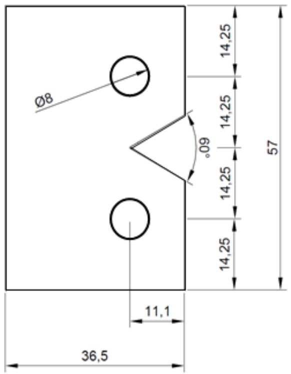
J-Integral (ASTM E1820)

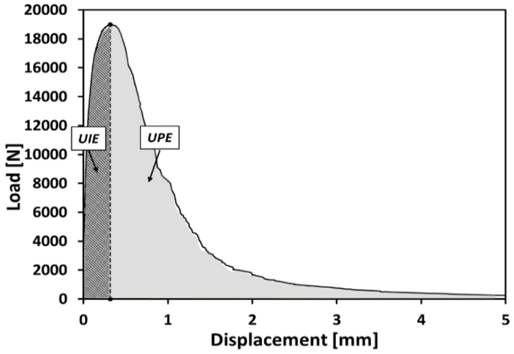




- Standard methodology
- Complex procedure
- Requires the measurement of crack advance
- Specimen size requirements are not satisfied for thin sheets
- The propagation energy includes the work of plastic deformation

Kahn Tear Tests (KTT)





- Easy to perform
- Complex loading mode that evolves from uniaxial tensile to bending
- The propagation energy includes the work of plastic deformation
- Not a material property

2. Fracture toughness evaluation of thin sheets

➢Fracture toughness in AHSS sheets?

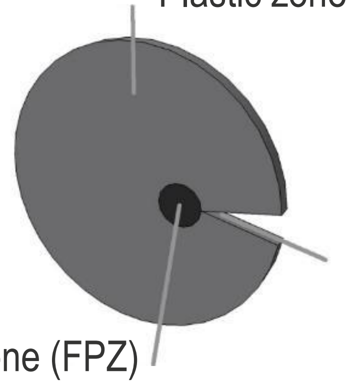
⇩

- The **E**ssential **W**ork of **F**racture (**EWF**) methodology is used to evaluate the fracture of thin plates on plane stress. Cotterell and Reddel (1977)
- It has been successfully applied in **polymer films** (ESIS TC4, 1993) and **ductile metals** (low C steel, Cu, Al)

2. Fracture toughness evaluation of thin sheets

DUCTILE FRACTURE: Fracture energy can be separated into two terms:

$$W_f = W_p + W_e$$



W_e, **essential work of fracture,** is related to damage, **surface creation** and necking, then it is **essential. TOUGHNESS**

W_p, **Plastic work**, is related to plastic deformation. It depends on the specimen size and geometry and the loading mode, then it is **no essential**

How to separate them?
→ The **Essential Work of Fracture (EWF) methodology**

2. Fracture toughness evaluation of thin sheets

- Ligament is completely yielded
- Plastic zone is confined to the notched ligament

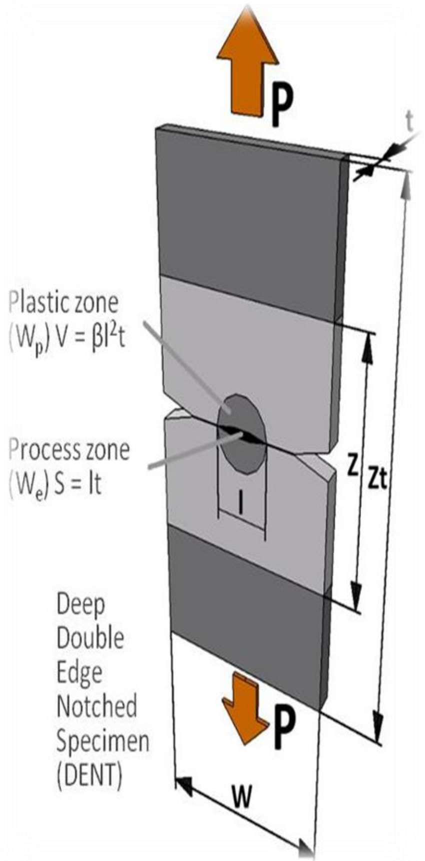
$$W_f = W_e + W_P$$

$W_P \propto$ plastic volume at initiation

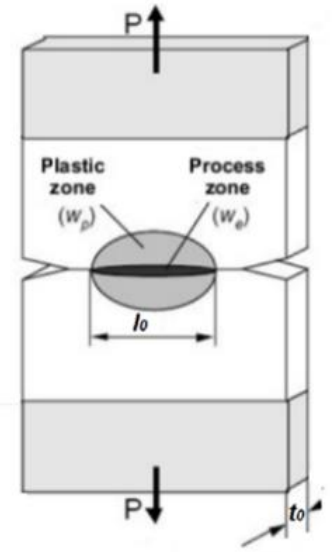
$W_e \propto$ fractured area

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

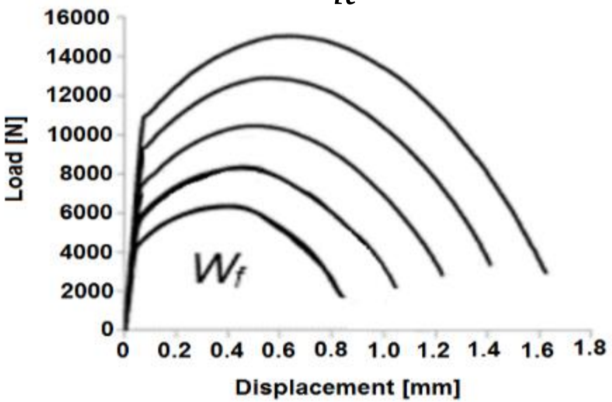
$$\frac{W_f}{lt} = w_f = w_e + \beta w_p l$$

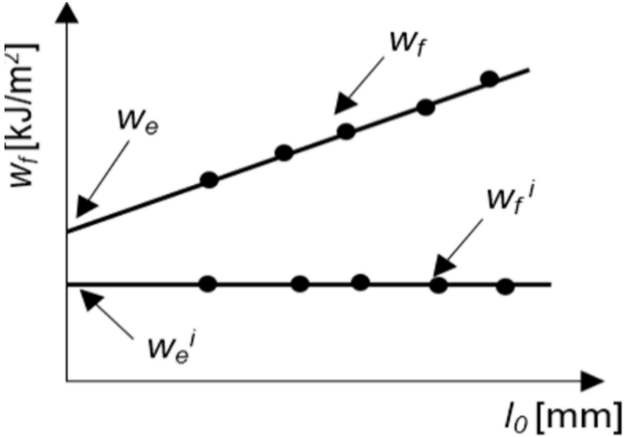


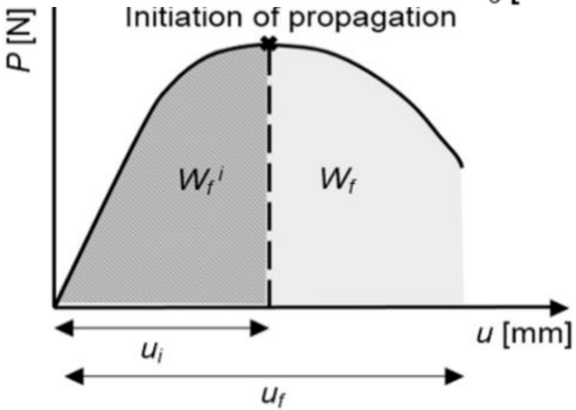
2. Fracture toughness evaluation of thin sheets



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

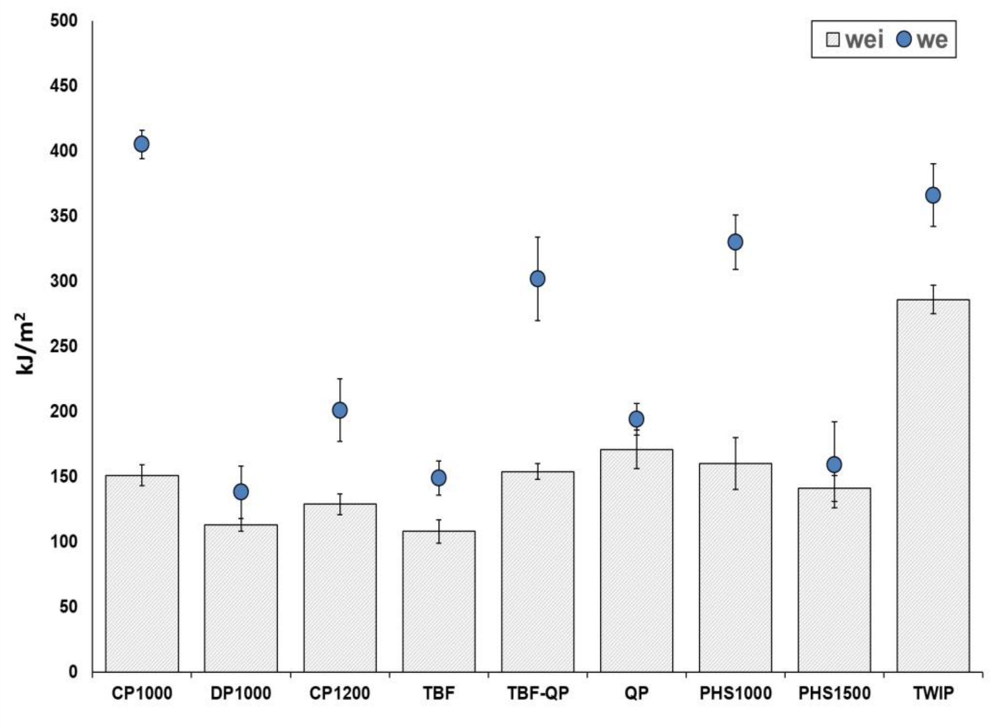


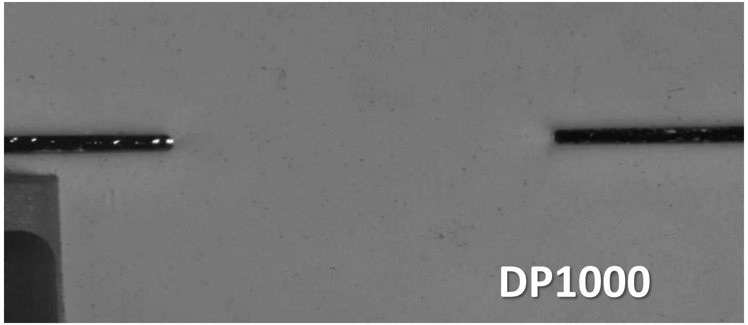


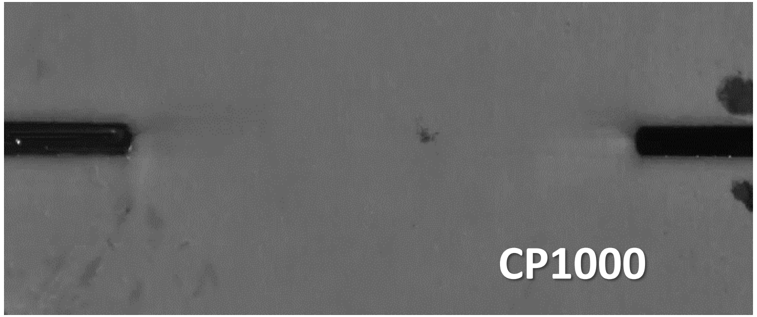


- ❑ No standard (ESIS protocol)
- ❑ Easy to perform
- ❑ Permits to separate crack initiation and crack propagation
- ❑ w_e^i is a material property equivalent to J_C

⇨ Comparison of toughness at crack initiation (w_e^i) and at fracture (w_e)





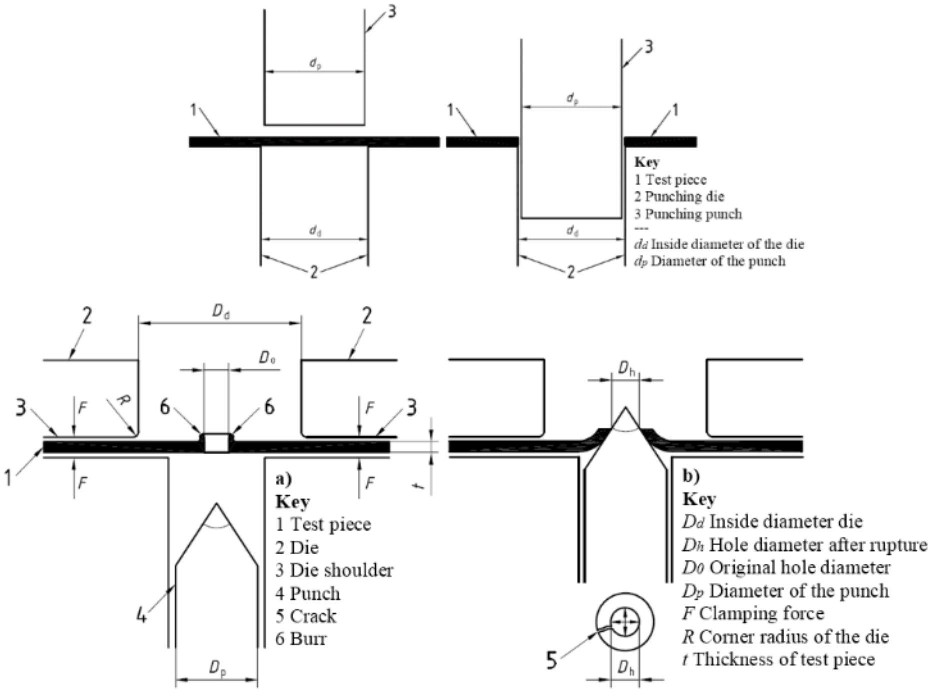


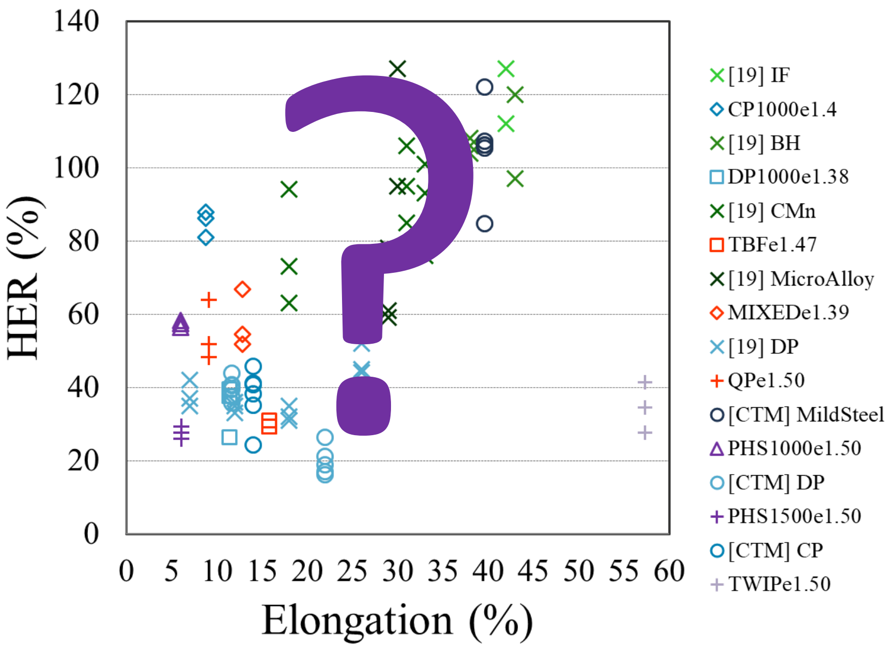
3. Fracture toughness as a material property

Outline

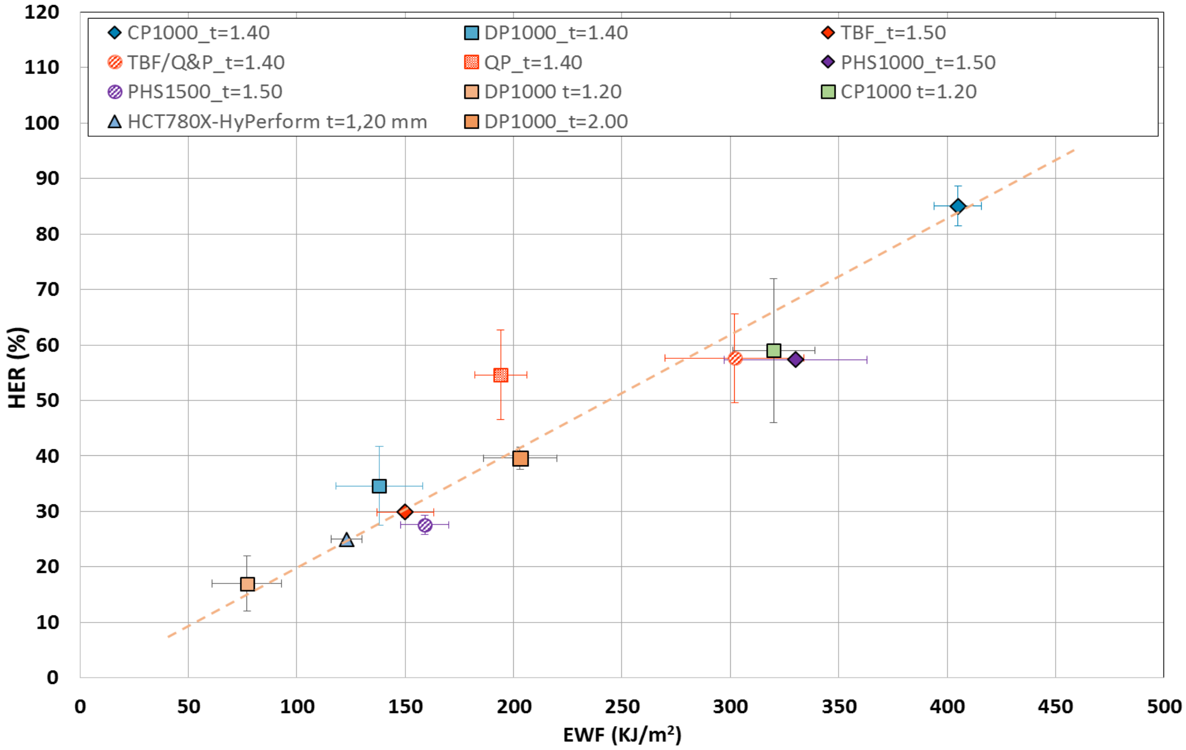
3. Fracture toughness as a material property

➢ STRETCH FLANGEABIITY: HOLE EXPANSION TEST (ISO 16630)



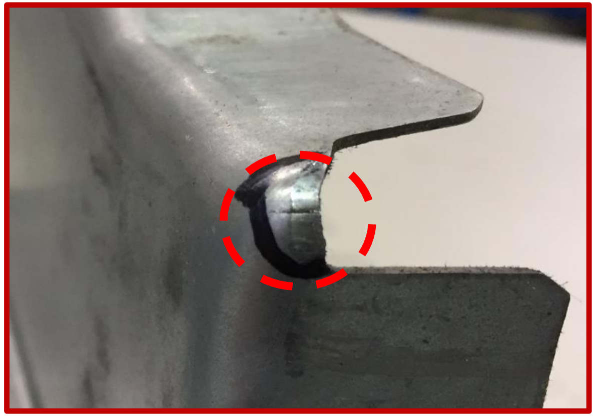


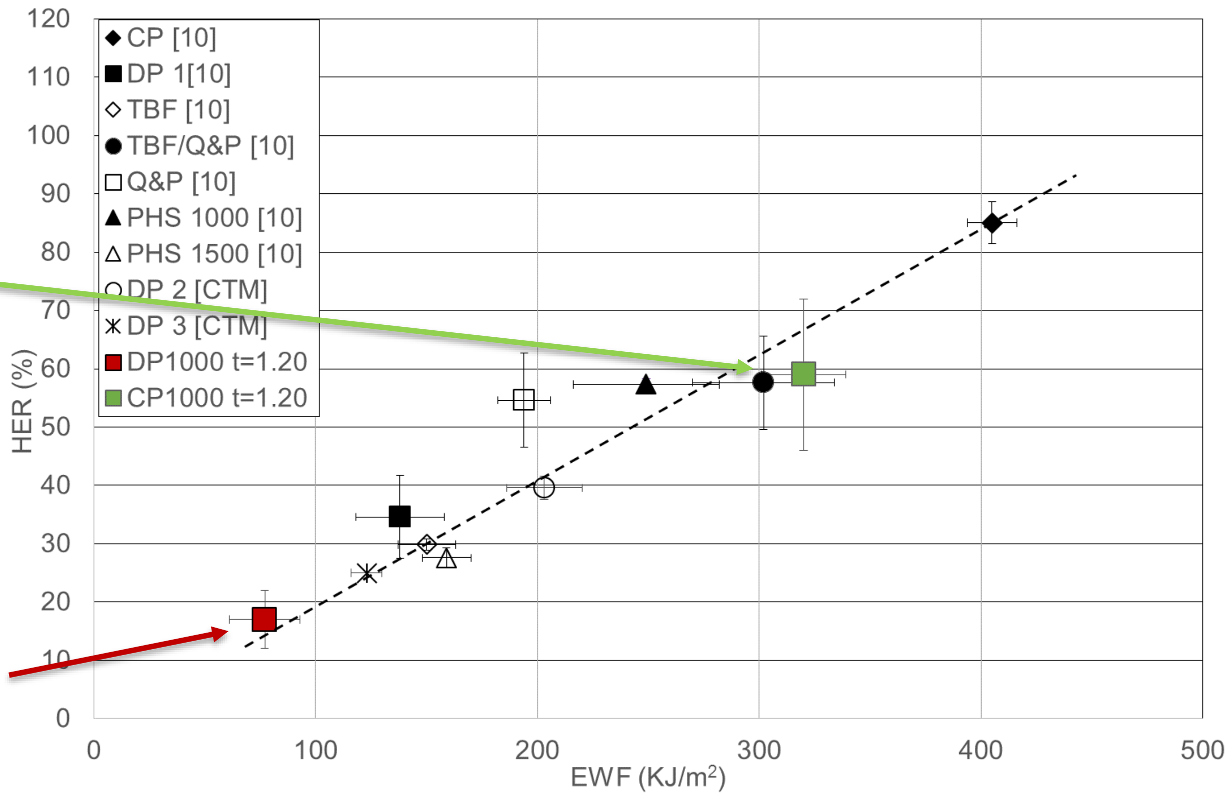
3. Fracture toughness as a material property



D. Casellas et al., Fracture Toughness to Understand Stretch-Flangeability and Edge Cracking Resistance in AHSS, Met. and Mat. Trans. A, 48 (2017) 86-94.

3. Fracture toughness as a material property

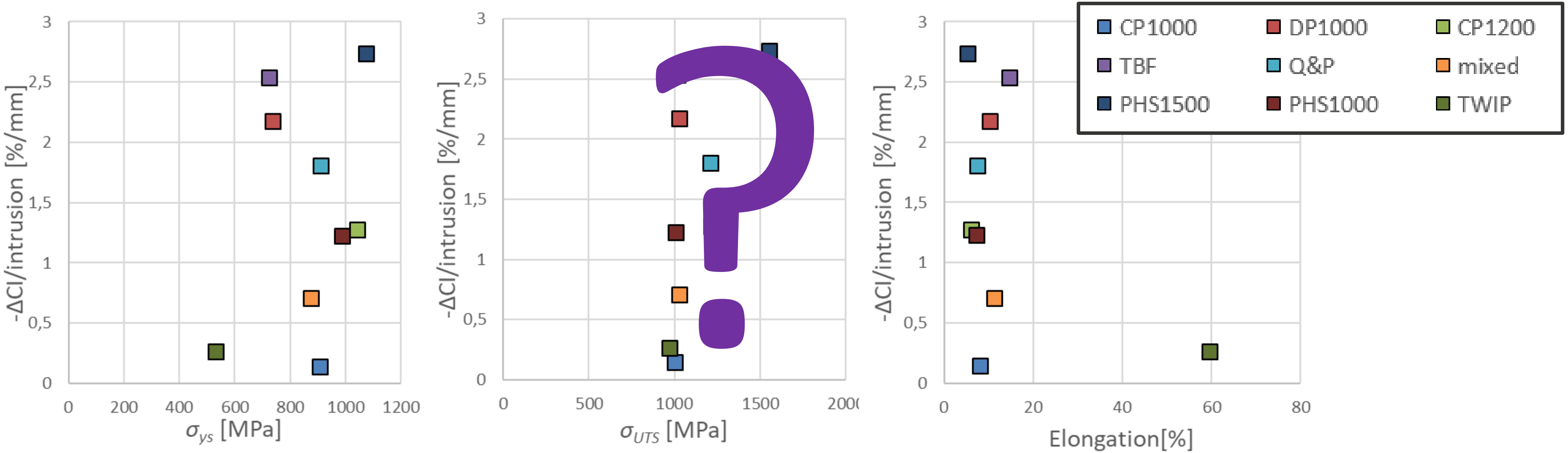




D.Frómeta, et al., Assessing edge cracking resistance in AHSS automotive parts by the Essential Work of Fracture methodology, J. Phys.: Conf. Ser. 896 012102 (2017)

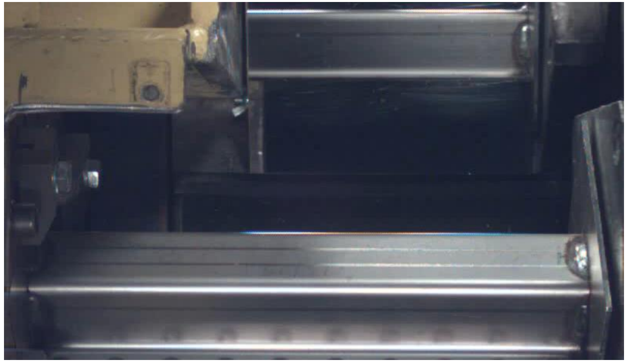
3. Fracture toughness as a material property

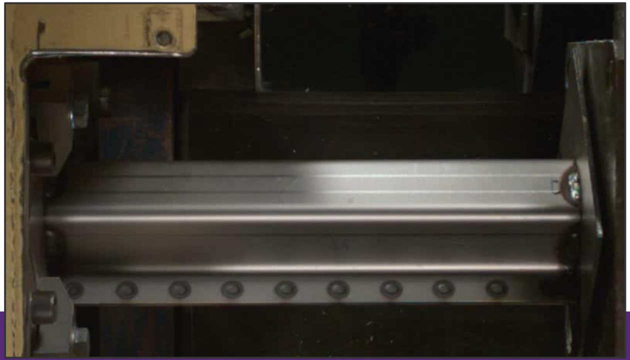
- **Crashworthiness** is a complex property to measure
- Impact tests are time consuming and expensive
- Crashworthiness cannot be estimated from tensile tests properties

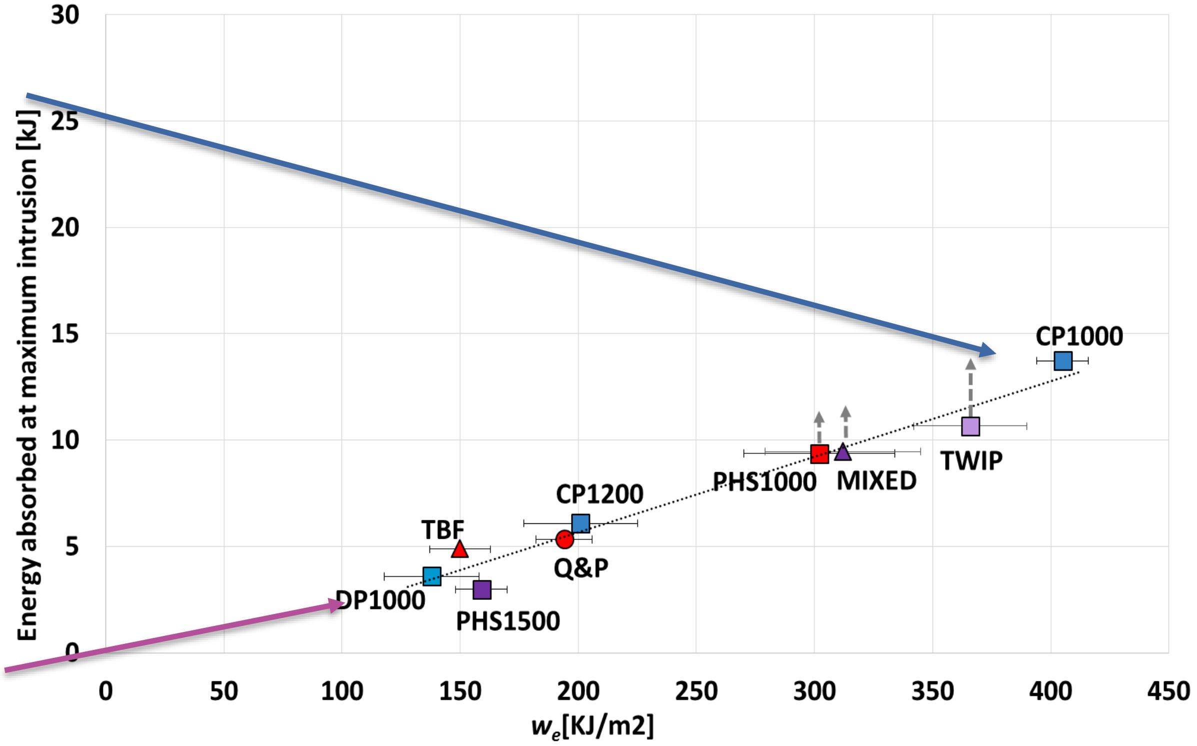


3. Fracture toughness as a material property

⇨ Crash resistance AHSS: crashworthiness



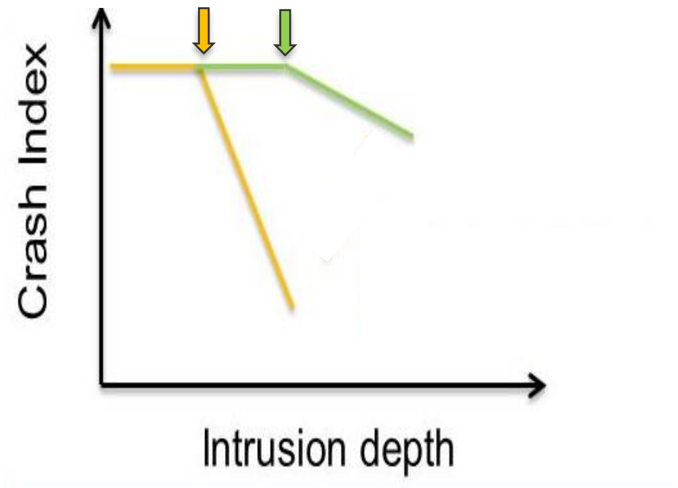


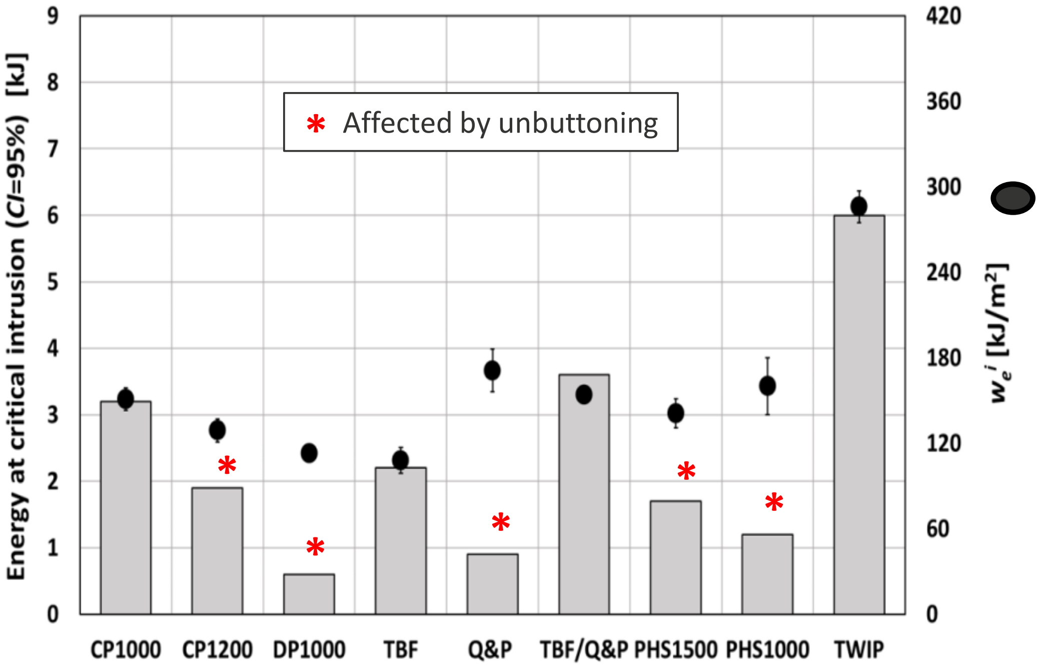


D.Frómeta, et al., On the correlation between fracture toughness and crash resistance of advanced high strength steels, Eng. Frac. Mech. 205 (2019) 319-332

3. Fracture toughness as a material property

⇨ Crash resistance AHSS: critical intrusion level

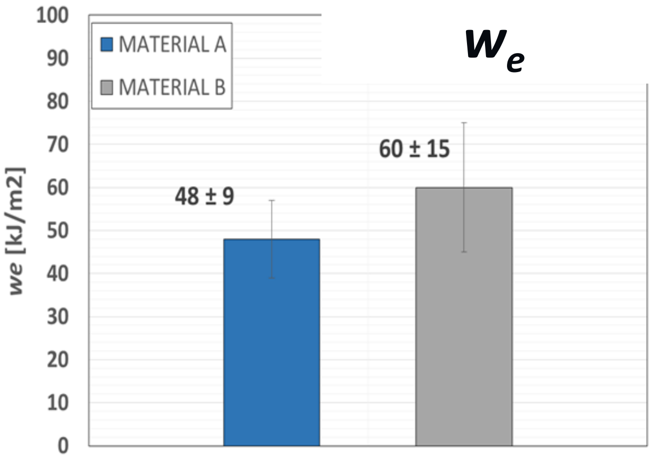


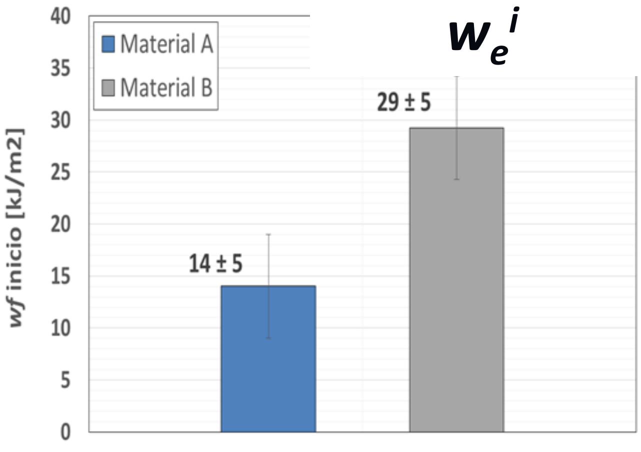


D.Frómeta, et al., On the correlation between fracture toughness and crash resistance of advanced high strength steels, Eng. Frac. Mech. 205 (2019) 319-332

3. Fracture toughness as a material property

⇨ Crash resistance Al alloys





➢ QUALITY CONTROL OF COIL PROPERTIES

- Fractures can unexpectedly occur in the workshop for some coils. Materials /coils within the metallurgical quality range, may give rise to cracking during part production
- Such fracture **cannot** be explained by using tensile tests properties or chemical composition
- Fractures **can** be understood by using **EWF, coil properties** can be assessed by **EWF**

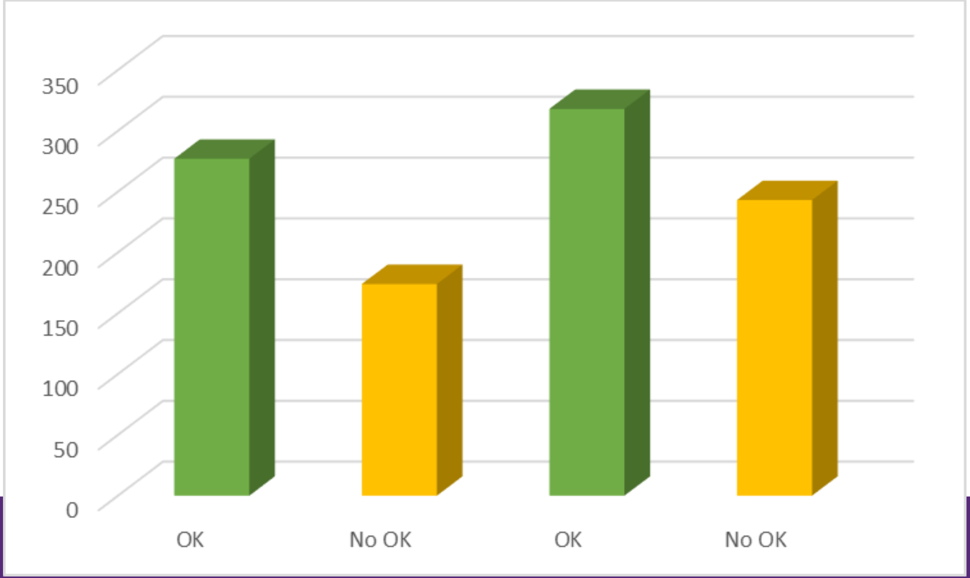
3. Fracture toughness as a material property

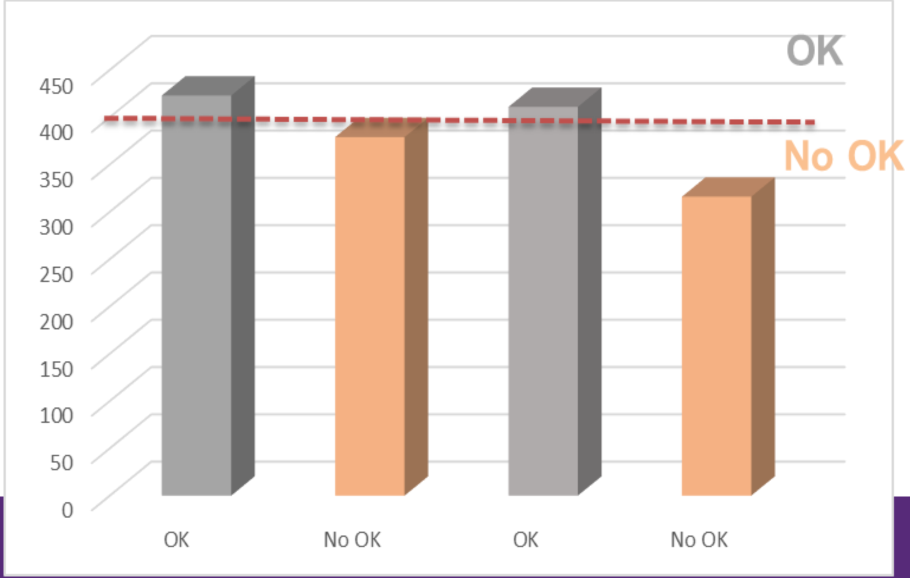
AHSS (UTS 800 MPa): Same nominal chemical composition, different steelmaker:

- No OK UTS = 850 MPa, Elongation 17%
  Fracture toughness 174-243 KJ/m^2
- OK, UTS =820 MPa, Elongation 16%
  Fracture toughness 277-318 KJ/m2

AHSS (UTS 1000 MPa): Same steelmaker, different heats

- Detection of coil quality
- Detection of coil differences (front vs tail)

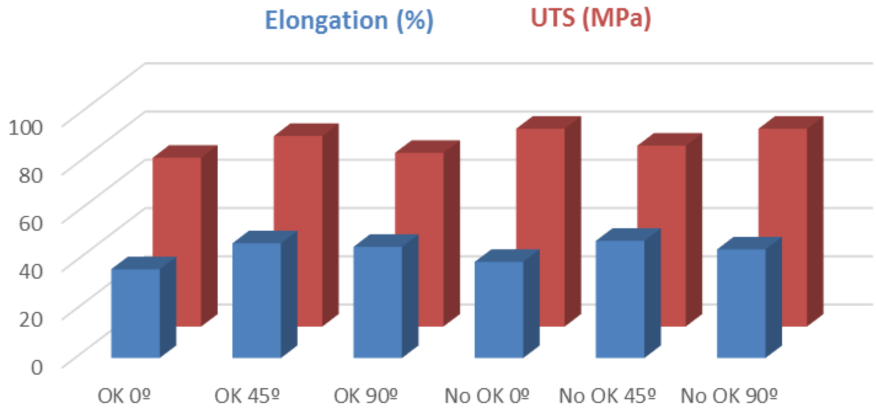


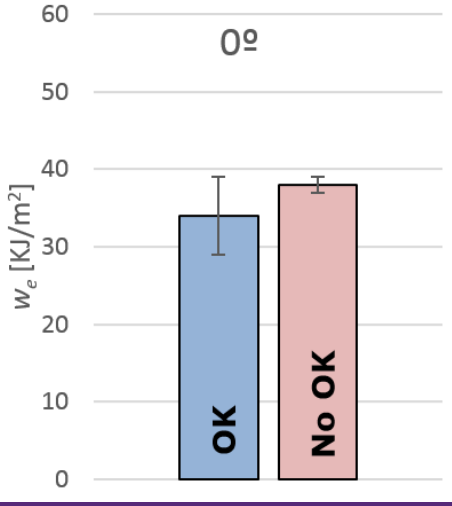


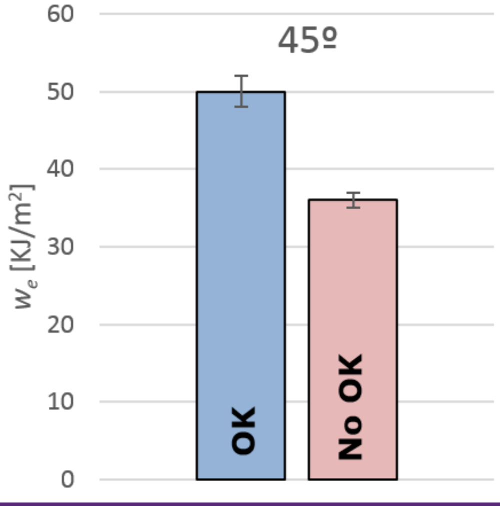
3. Fracture toughness as a material property

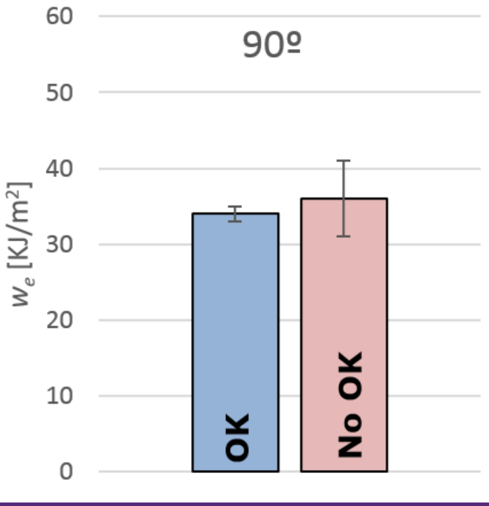
Aluminum serie 1xxx

- Fractures from different coils in stamping of embossed Al sheets
- Similar elongation and UTS
- Different **fracture toughness** in specimens extracted at 45 º from rolling direction









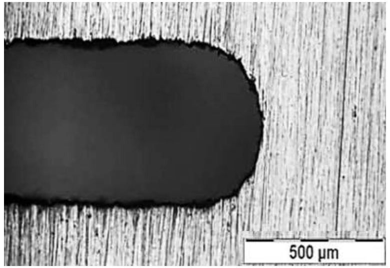
4. New device to measure fracture toughness

Outline

4. New device to measure fracture toughness

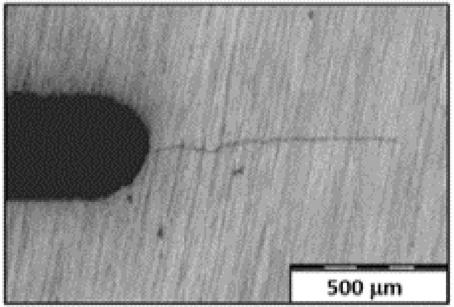
- Notched specimens:

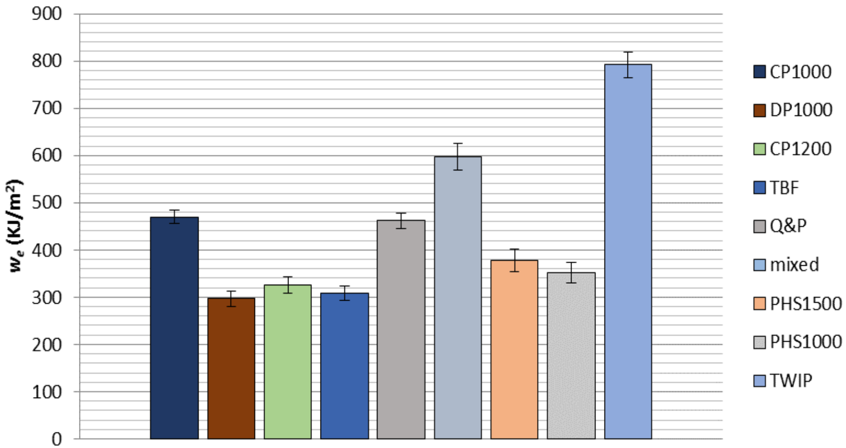
  notch by EDM (**ρ≈150 µm**)

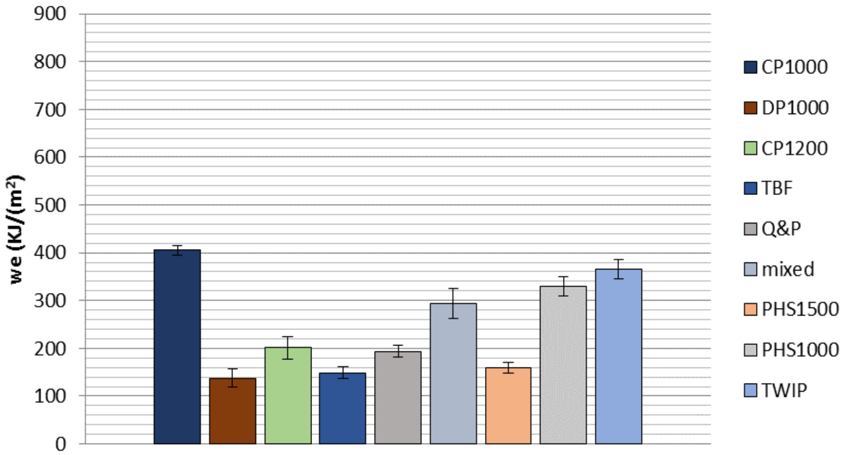


- Pre-cracked specimens:

  Notch + fatigue pre-cracking

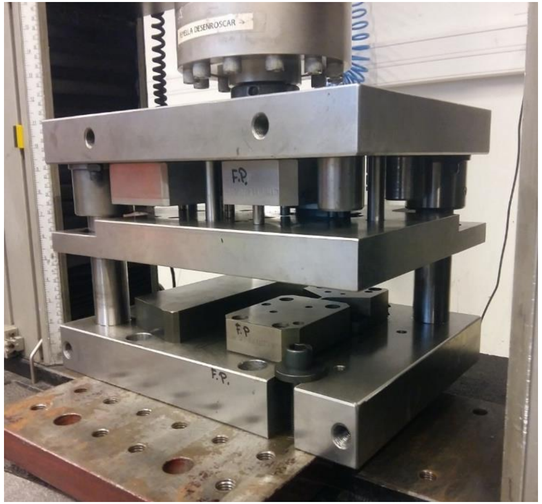


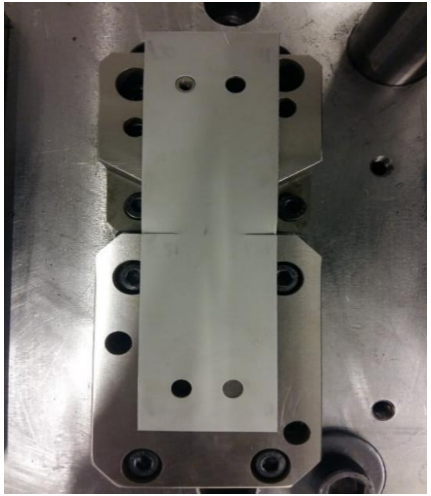


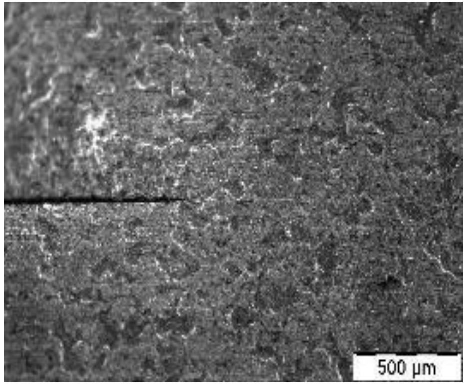


4. New device to measure fracture toughness

New method: Mechanically sheared notches

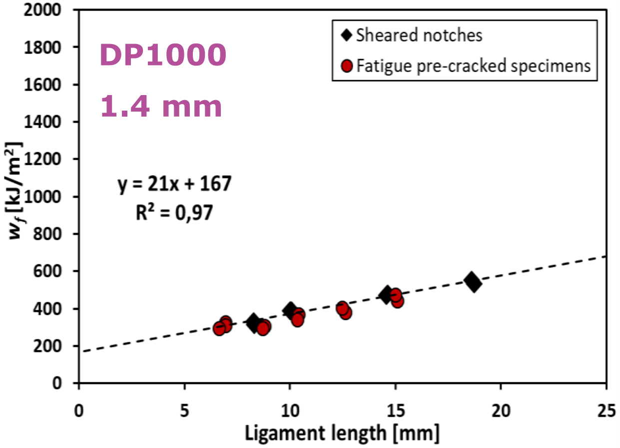


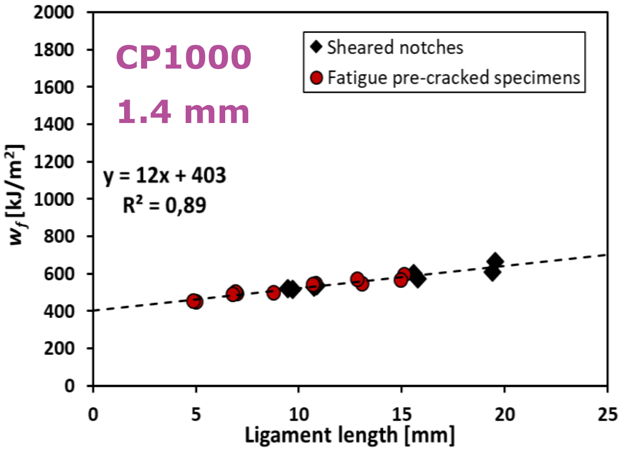


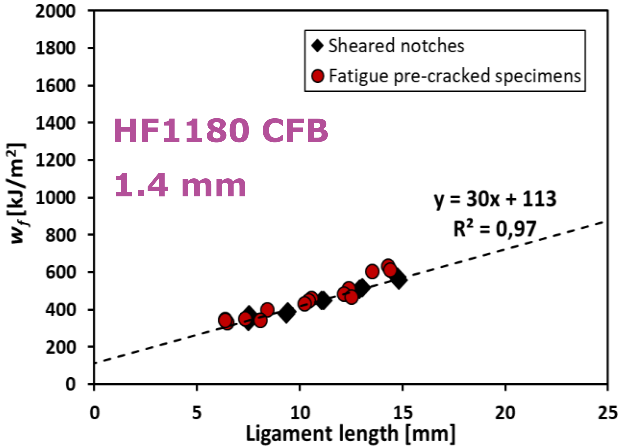


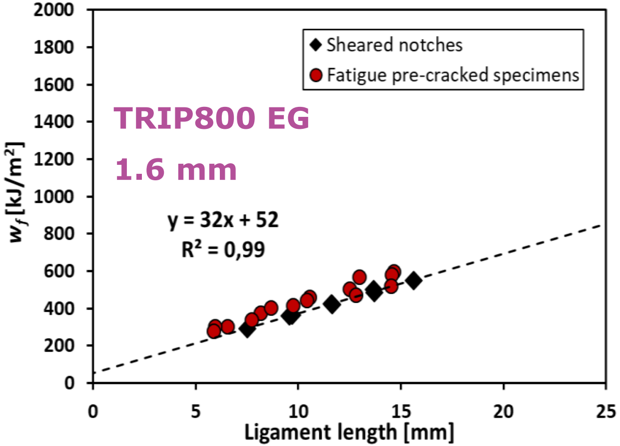
European Patent number EP18382321.0

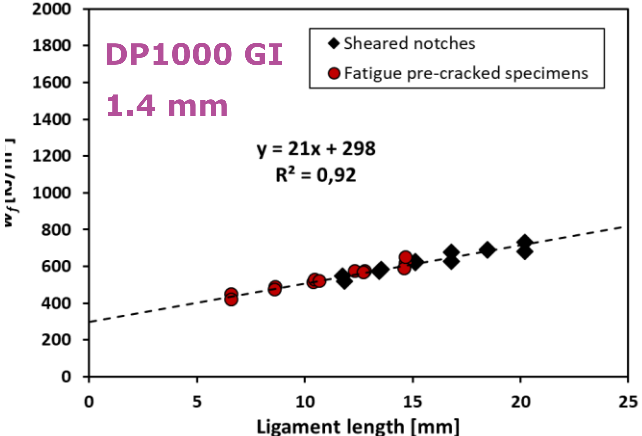
4. New device to measure fracture toughness

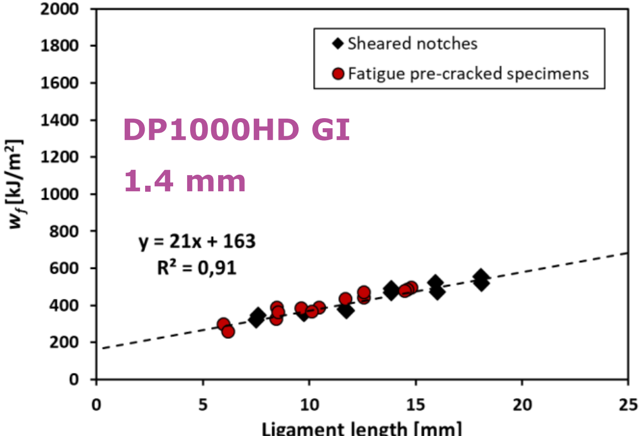












4. New device to measure fracture toughness

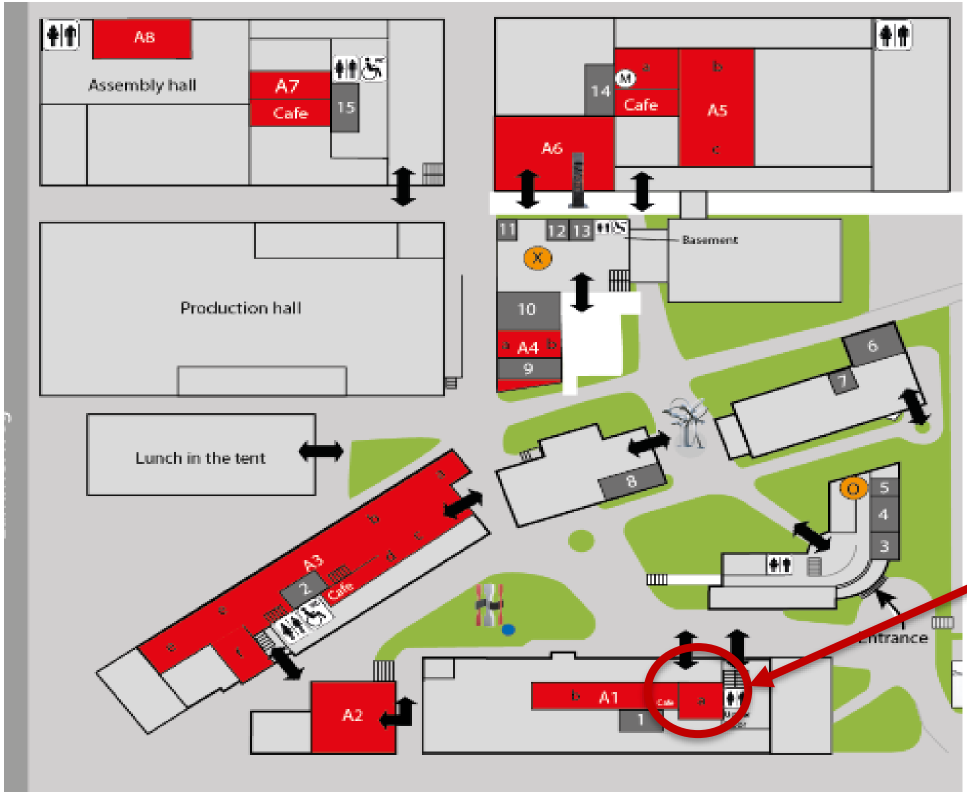
Benefits	New Device	Fatigue pre-cracking
Time consumption	< 1 h (like a tensile test)	1 week
Test requirements	Tensile testing machine + shearing tool	Tensile testing machine + Fatigue machine
Test cost	Cheap	Expensive
Reliable results	Yes	Yes
Fast	Yes	1 week
Crashworthiness and edge cracking	Yes	Yes
Workspace	Production facilities and external labs	Only laboratories

5. Conclusions and future works

5. Conclusions and future works

- **Fracture toughness** is a suitable material property to predict and understand cracking problems in high strength metal sheets.
- The **new testing device** allows a fast and reliable measure of **fracture toughness** in thin sheet materials.
- Fracture toughness values can be used to predict edge cracking, crashworthiness in **materials development** and to check coil quality or select the raw material supplier in **sheet metal forming**
- The applicability to **other high strength materials** as polymers, CFRP, or castings, is under study: OptiLightMat, FormPlanet.

Stand TestXpo 2019



Building A1 Academia

Further questions/interests?

Contact: Dr. Daniel Casellas, daniel.casellas@eurecat.org