IMPERIAL

High-Rate Fracture Testing Methods

Fixed Energy Input (Pendulum) vs. Speed Controlled (Servo-hydraulic) Experimental Procedures

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DSDS 24 – Cranfield University, Museum of the Great Western Railway

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Standard ‘Rapid’ Fracture Methods

Toughness changes with Speed

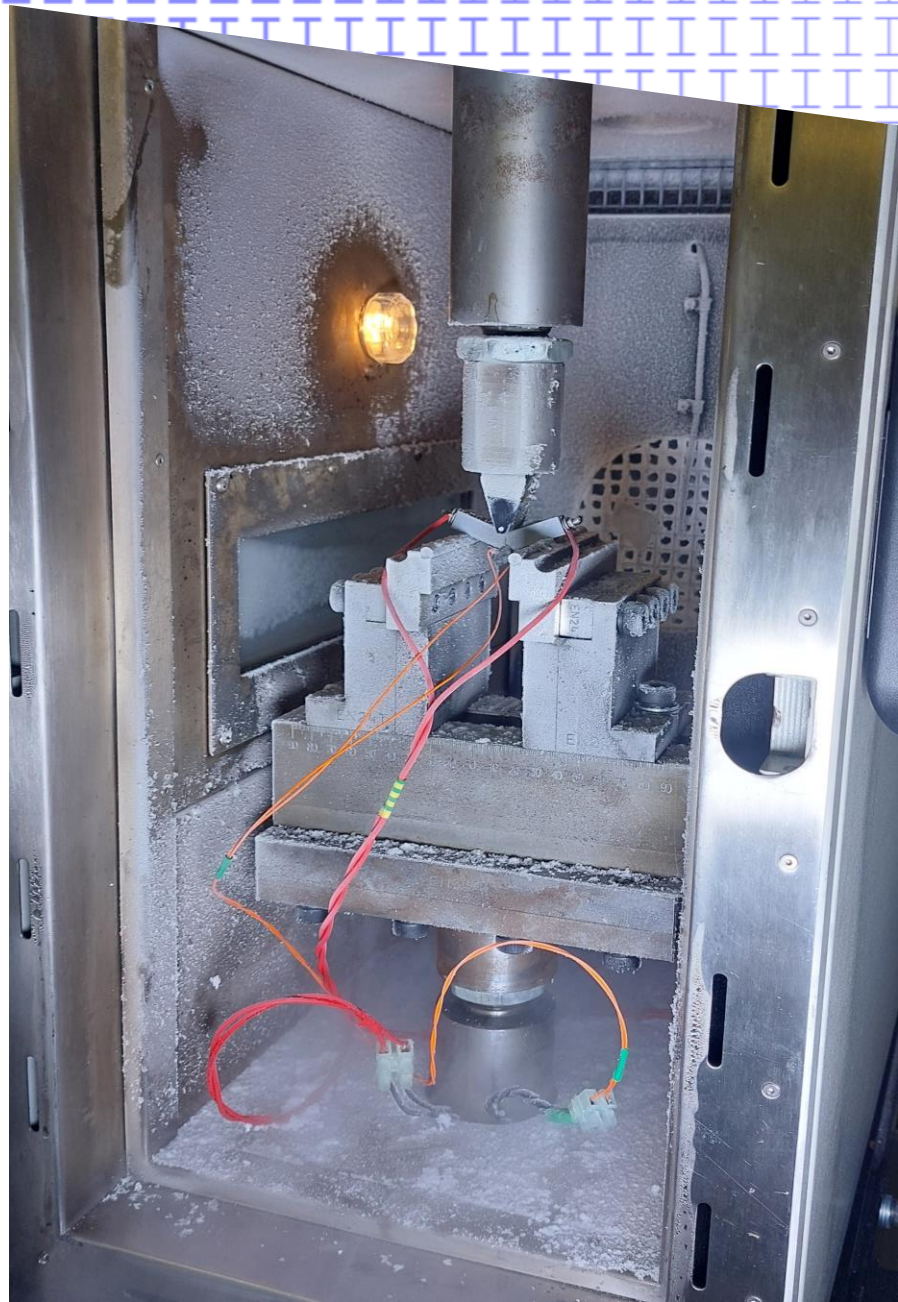
ASTM E1820-***Ap.14&17***
ASTM E399-***Ap.10***
BS 7448-3-***Ap.A***
BS ISO 26834:2015

Same equations as static: Assume Negligible Inertia

Charpy preferred - mature technology
- Charpy Samples 10x10x55mm, notch and ½ Pre-crack
- **Prone to Plastic Collapse**

“such tests do not comply to valid specimen sizes but can be used as part of research and quality control” ASTM-E1820-23b

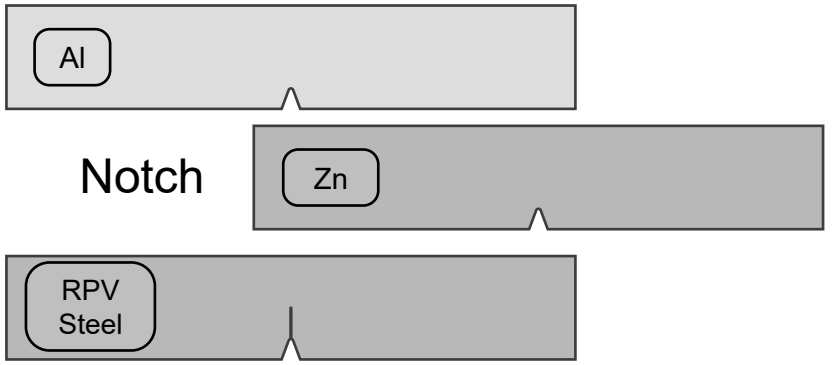
High uncertainty ∴ Large safety factors
Excessive conservatism



Standard ‘Rapid’ Fracture Methods

Charpy (Pendulum) vs. VHS INSTRON (Servo-hydraulic)

Readily Available	Little Discussion
Fixed Energy Input	Active Energy Input
Loose Speed during Test	Maintain Speed



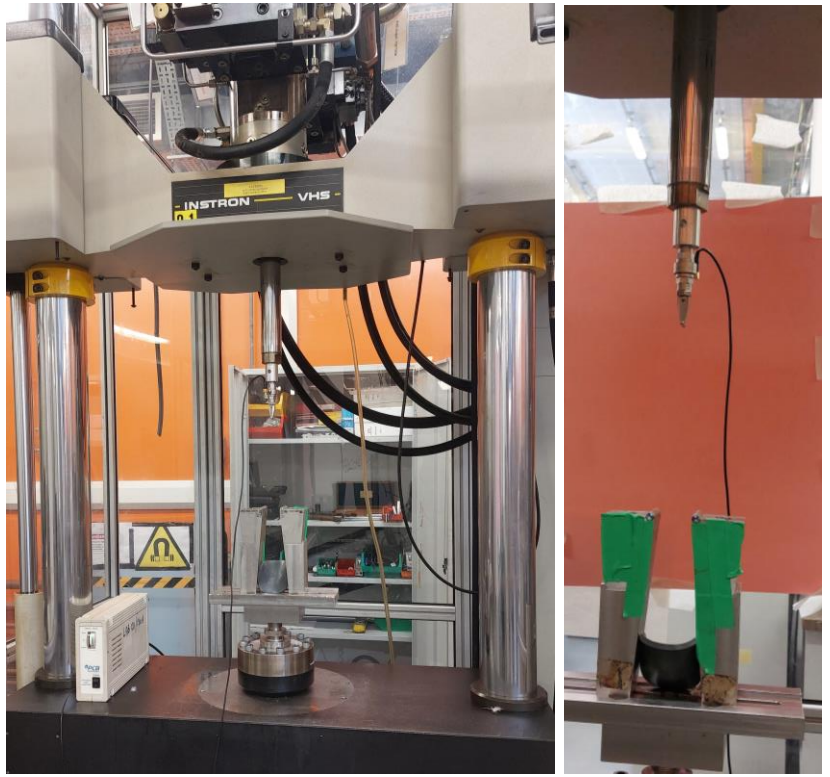
Instrumented Charpy

5.24 m/s

~310 strain/s

Fixed 450J input

Active Energy input

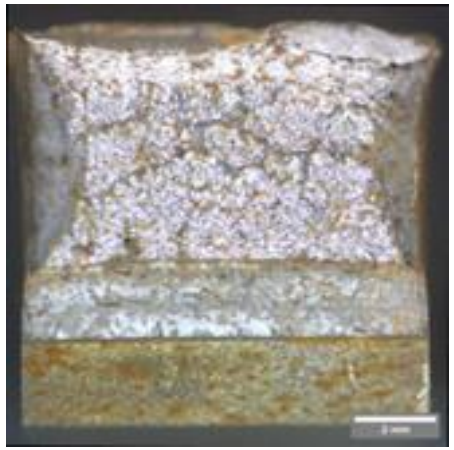


VHS INSTRON

Does speed control alter fracture response

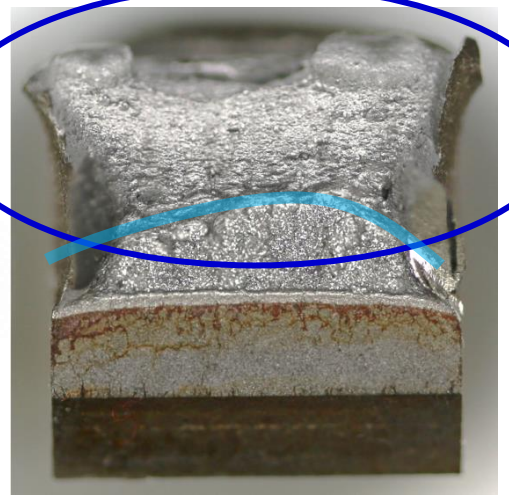
Results

RPV Steel – Pre-Crack



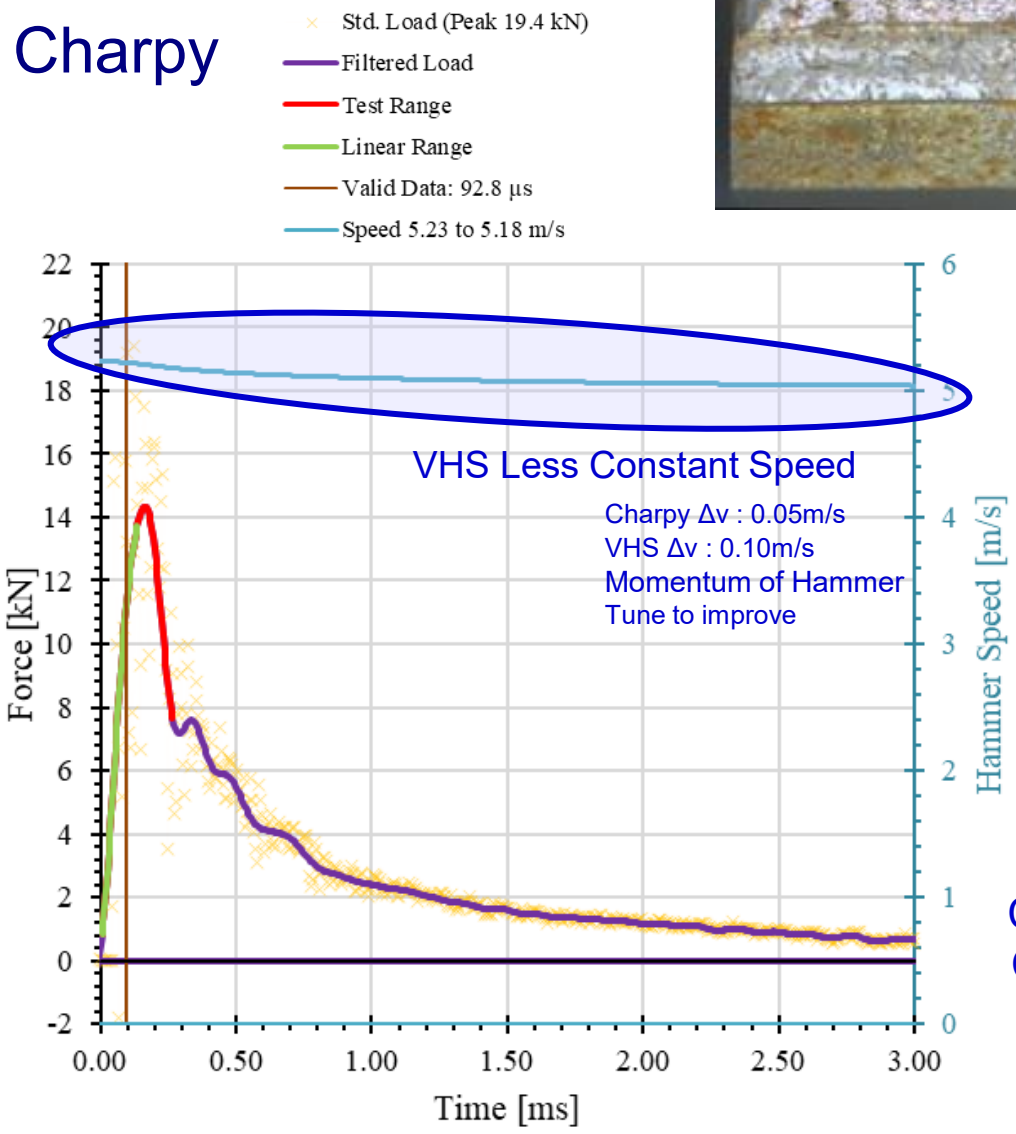
5mm

More ductile end [Post-collapse]



Same Feature [Collapse]

Charpy



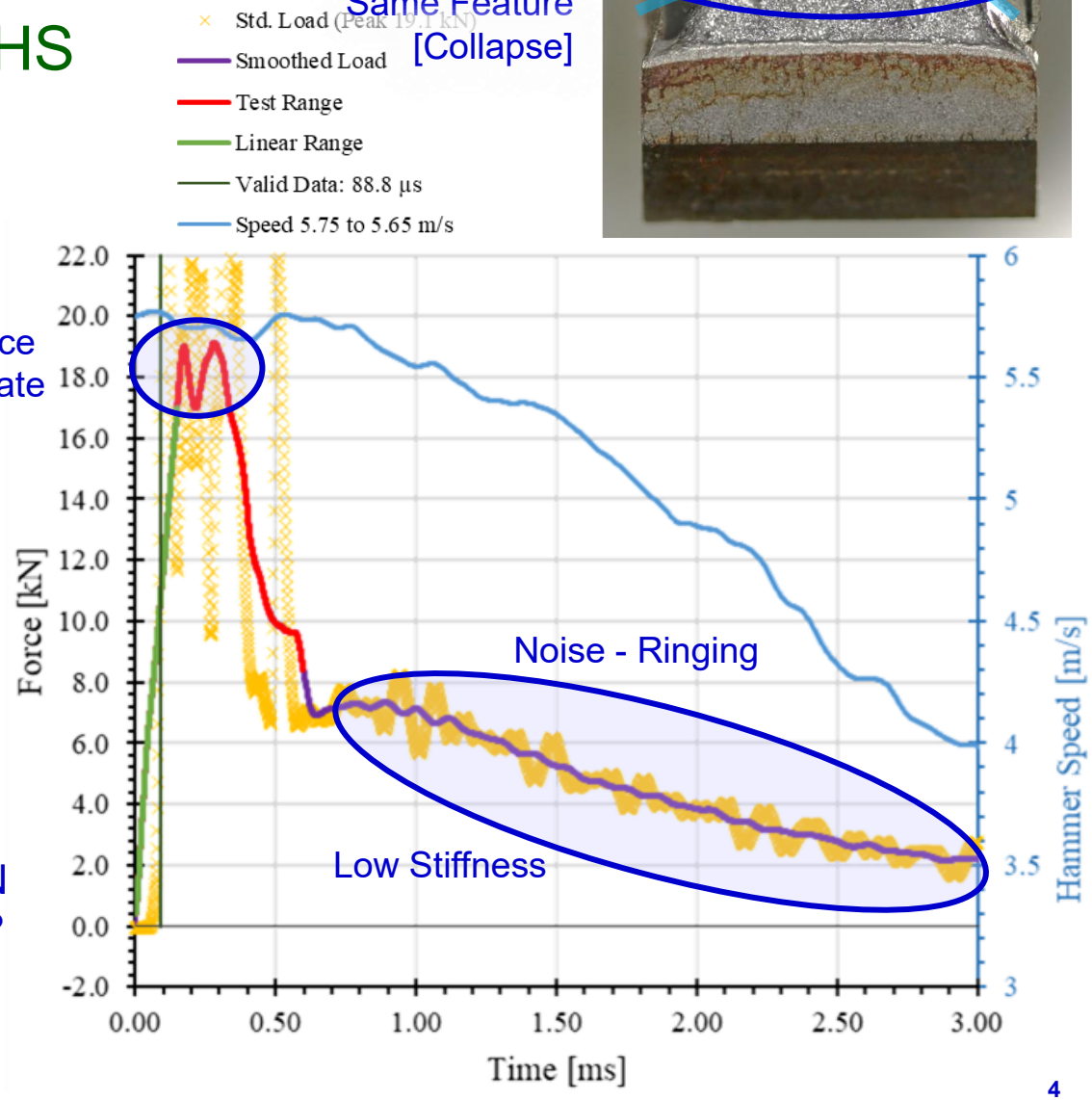
VHS Less Constant Speed

Charpy Δv : 0.05m/s
VHS Δv : 0.10m/s
Momentum of Hammer
Tune to improve

Higher Peak Force
Higher Sample rate

Similar Profile
Collapse 7.5 kN
Charpy Faster?
Compliance delay?

VHS



Noise - Ringing

Low Stiffness

Results

Dynamic Validity

Use of Static Equations

Assume Inertia effects are negligible

Nakamura [1986] SEN(B) – Tim 93µs

$$\tau = DS\frac{H}{C_0} \cong 23.8\frac{H}{C_0}$$

Standards

minimum time of test (t_m)

ASTM E39 1,000µs

ASTM E1820 $t_m > 2$ 68µs

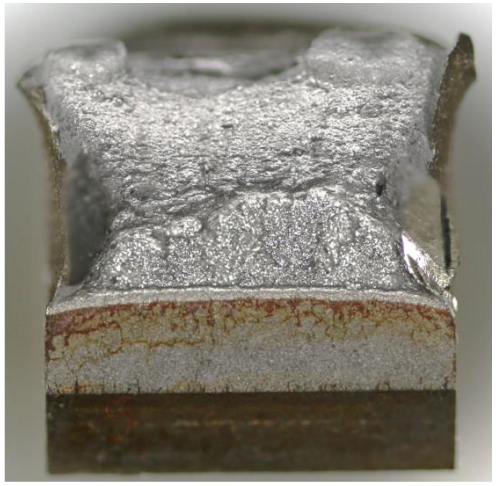
BS 140µs

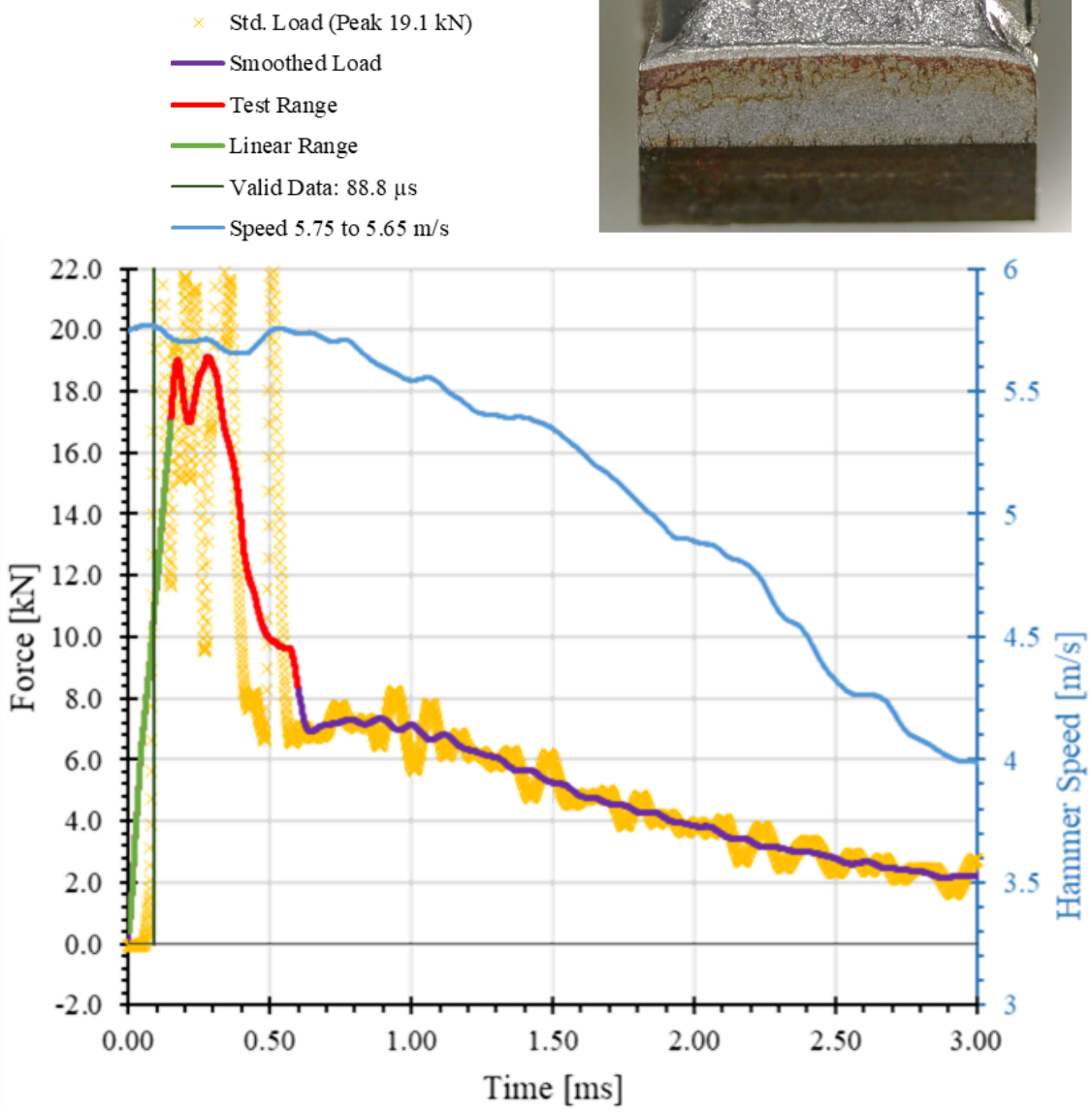
Stress Equilibrium

3x reflections $3 \cdot \frac{D}{C_0}$

Charpy 12µs VHS 10µs

5mm





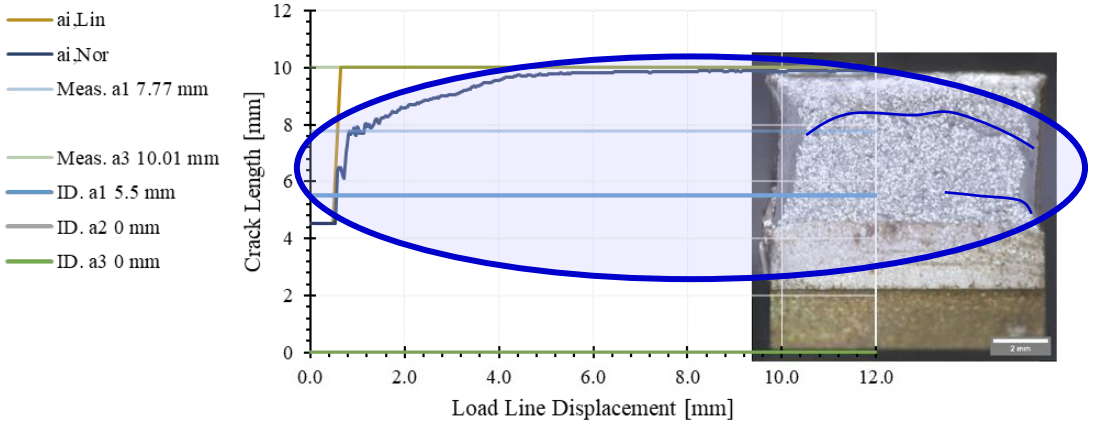
Results

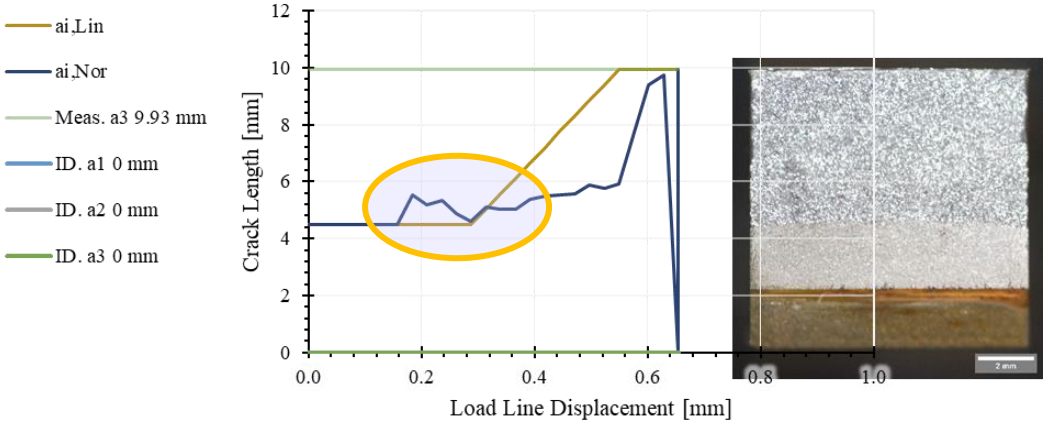
Crack Length Monitoring

Normalisation – Adjusted fit to normalised load history

Charpy

Normalisation – Fits well
Features show from load history

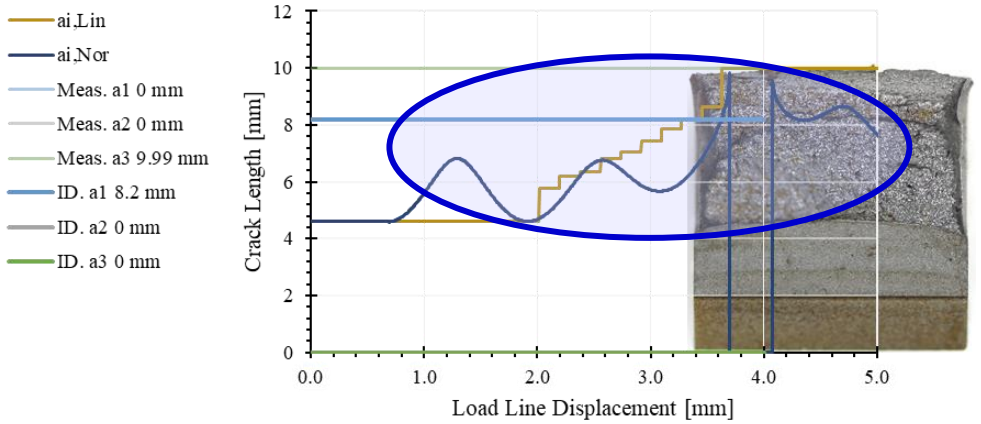


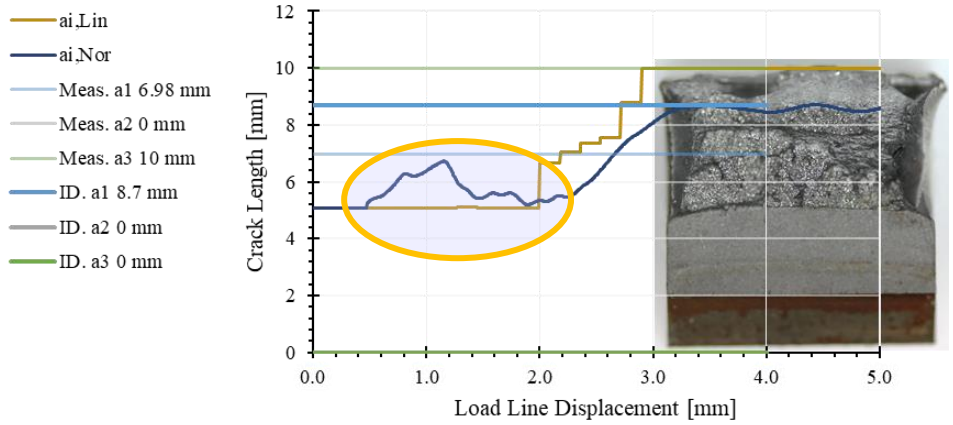


Linear – Similar Initiation
Norm. suggests earlier.
Blunting? Settling on supports?

VHS

Normalisation
Fit open to personal interpretation

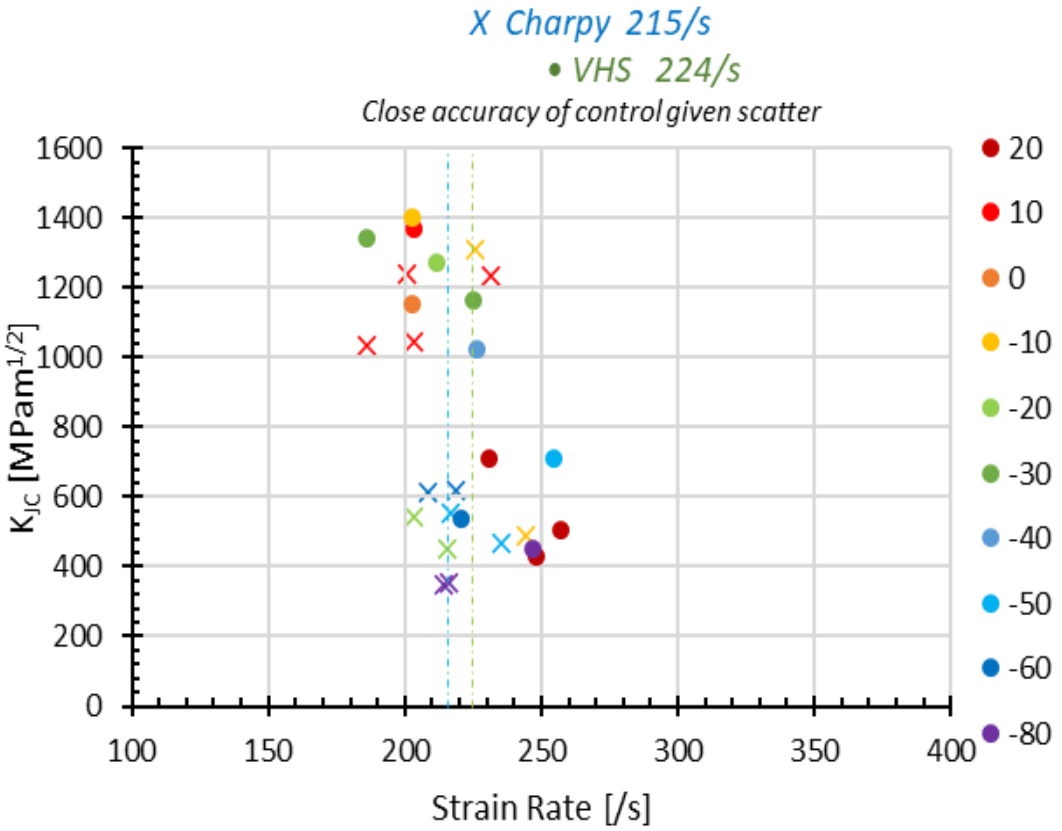




Linear – Assume crack growth from Max load to end of test
Generally seen as conservative but acceptable

Pre-Crack

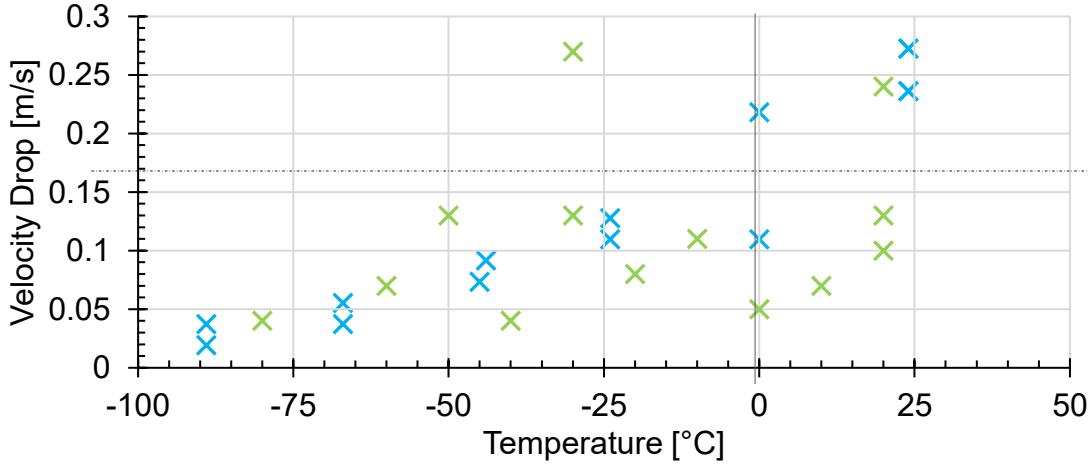
The Good

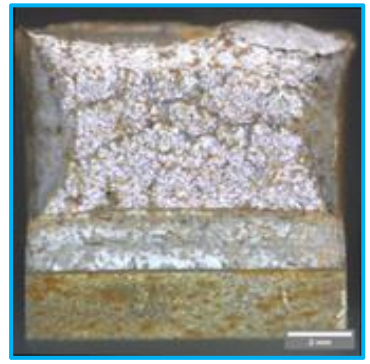


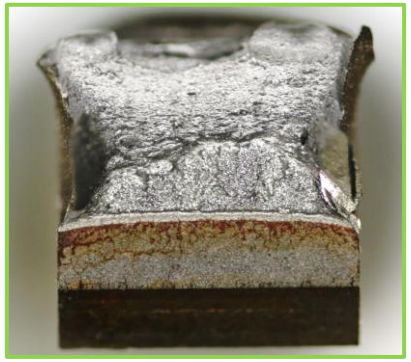
$\Delta v_{ave} = 0.11\, m/s$
± 0.12

Good Speed Control

~ Proportional to energy absorbed





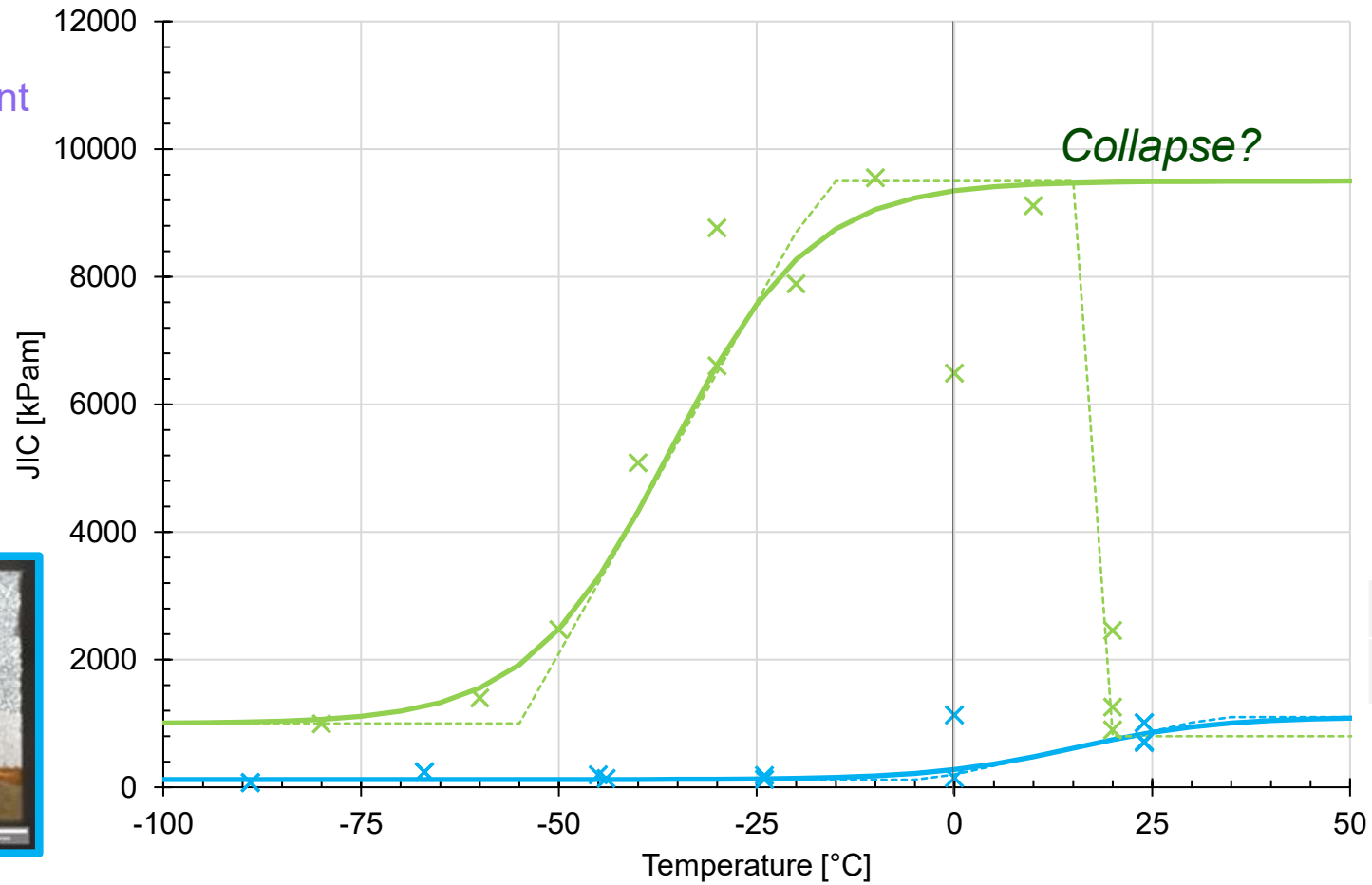


Pre-Crack

Charpy more reasonable values.
Better data analysis needed in VHS to effectively compare.

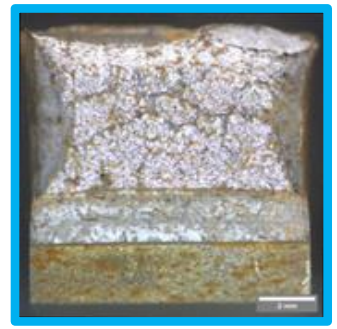
The Bad

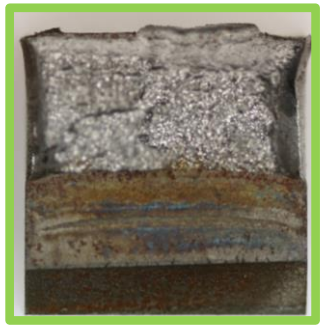
Very Different

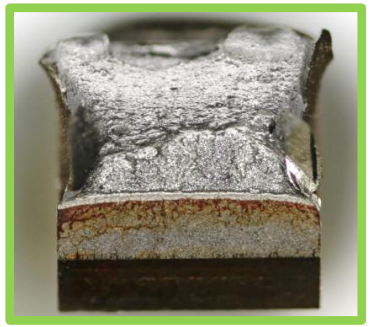


Charpy Results compare well with previous work

BDTT	-36	15	°C
~T_0	-135	-65	°C



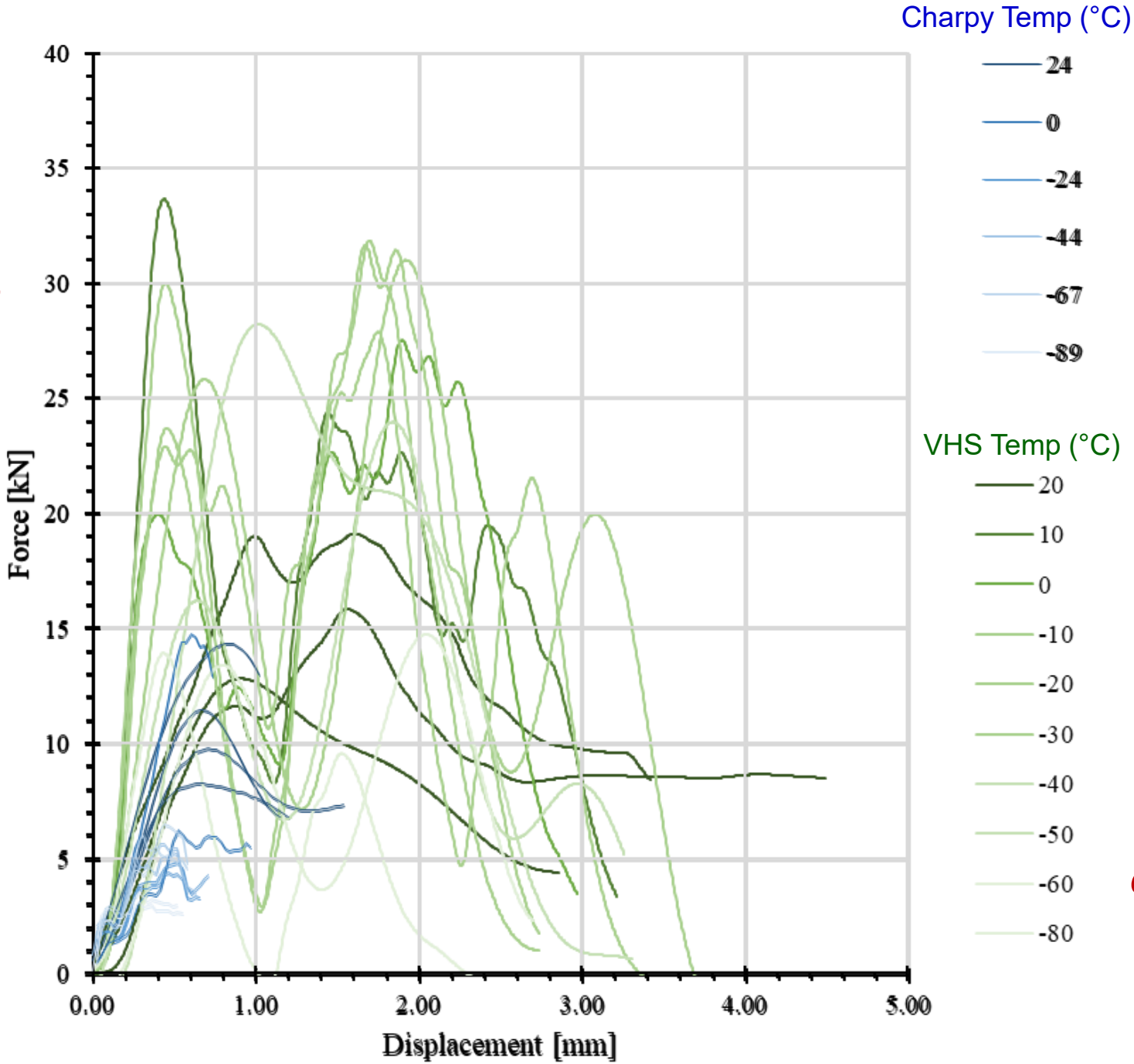




Pre-Crack

The Ugly

Impact ringing adding to initial load – artificially raising peak load

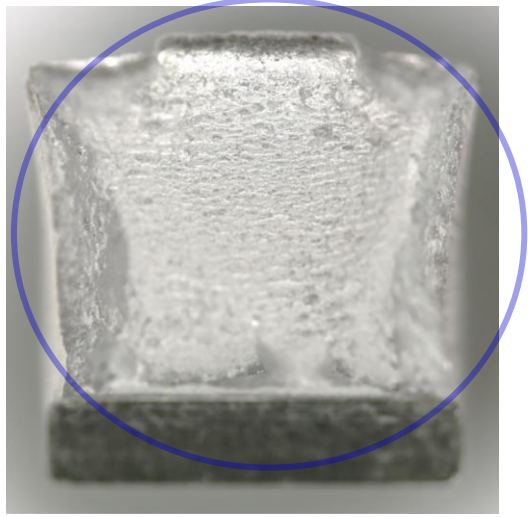


Ringing makes end of fracture difficult to identify

Results

Aluminium – Ductile

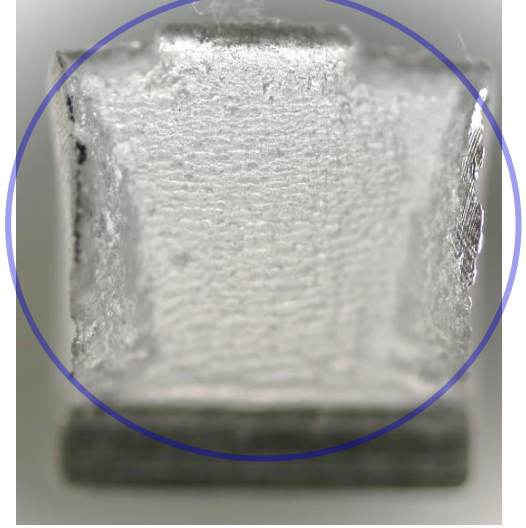
Charpy

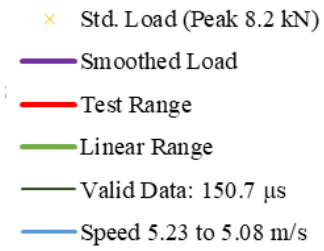


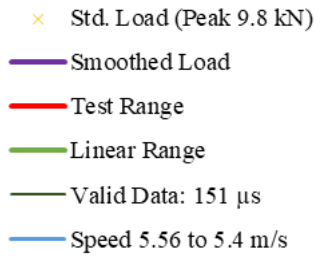
5mm

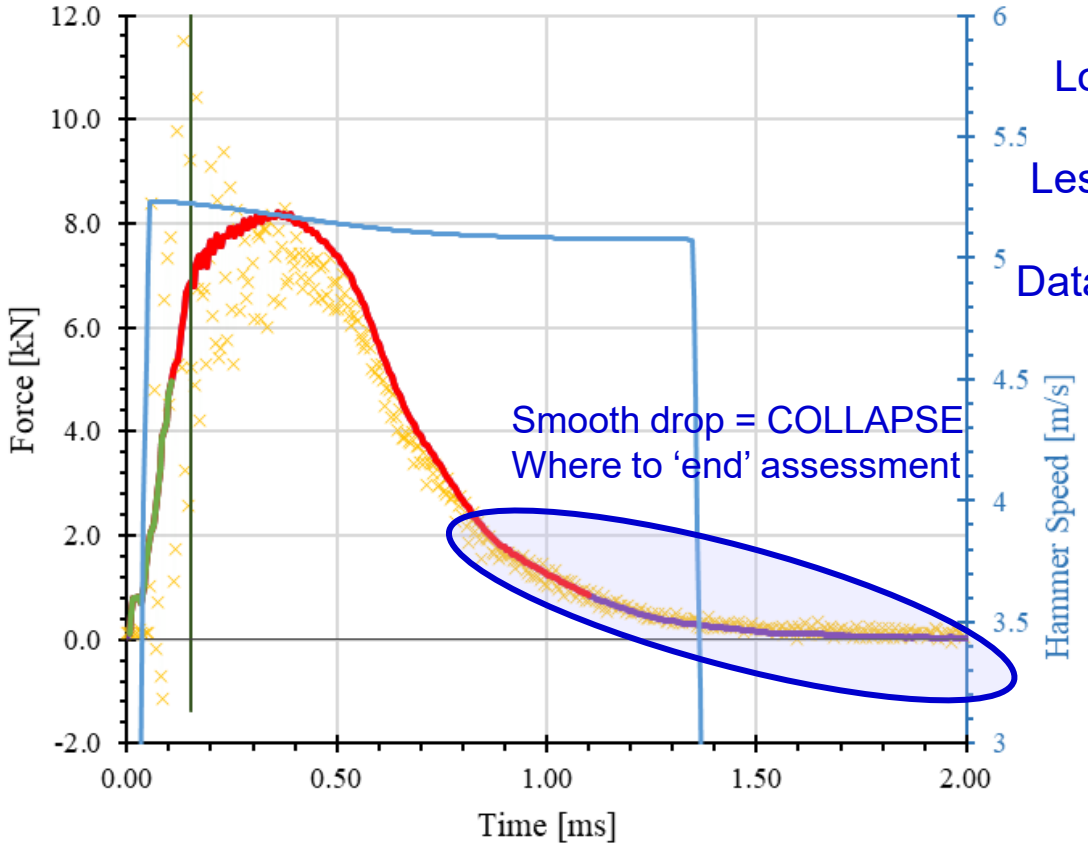
Same Feature
[Collapse]

VHS





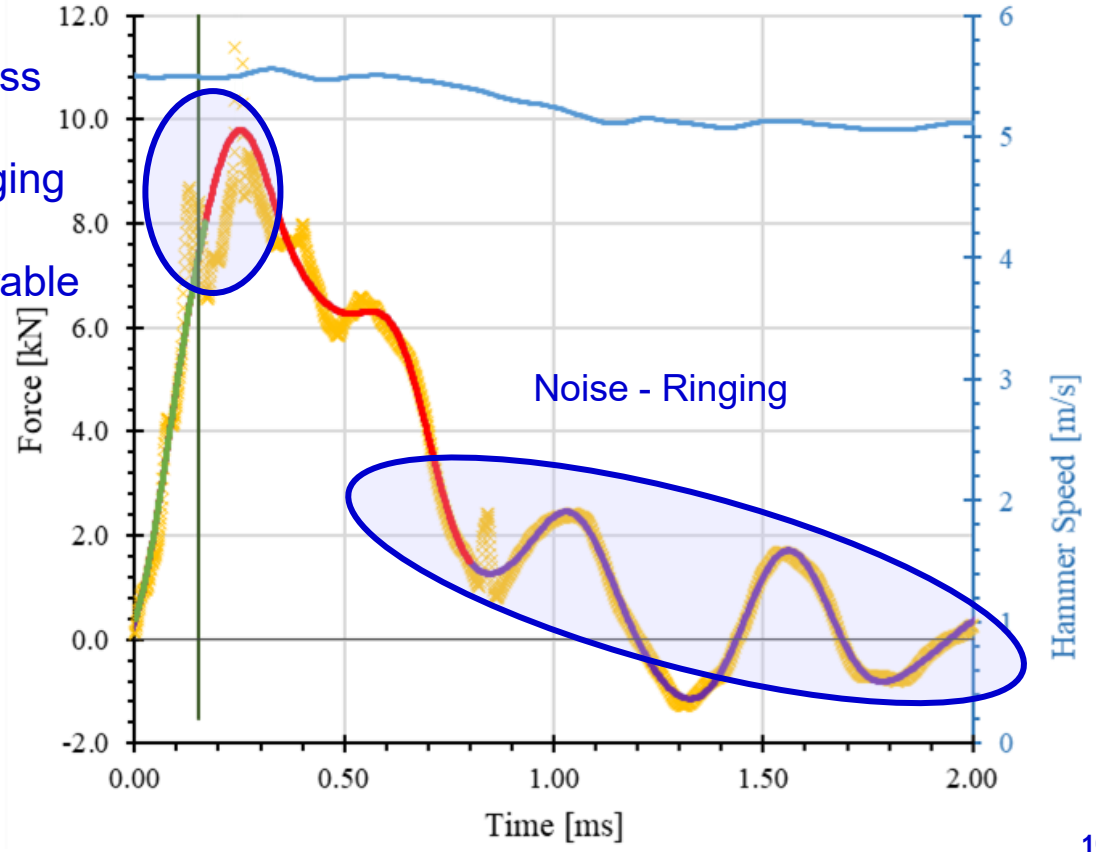




Lower Stiffness

Less initial ringing

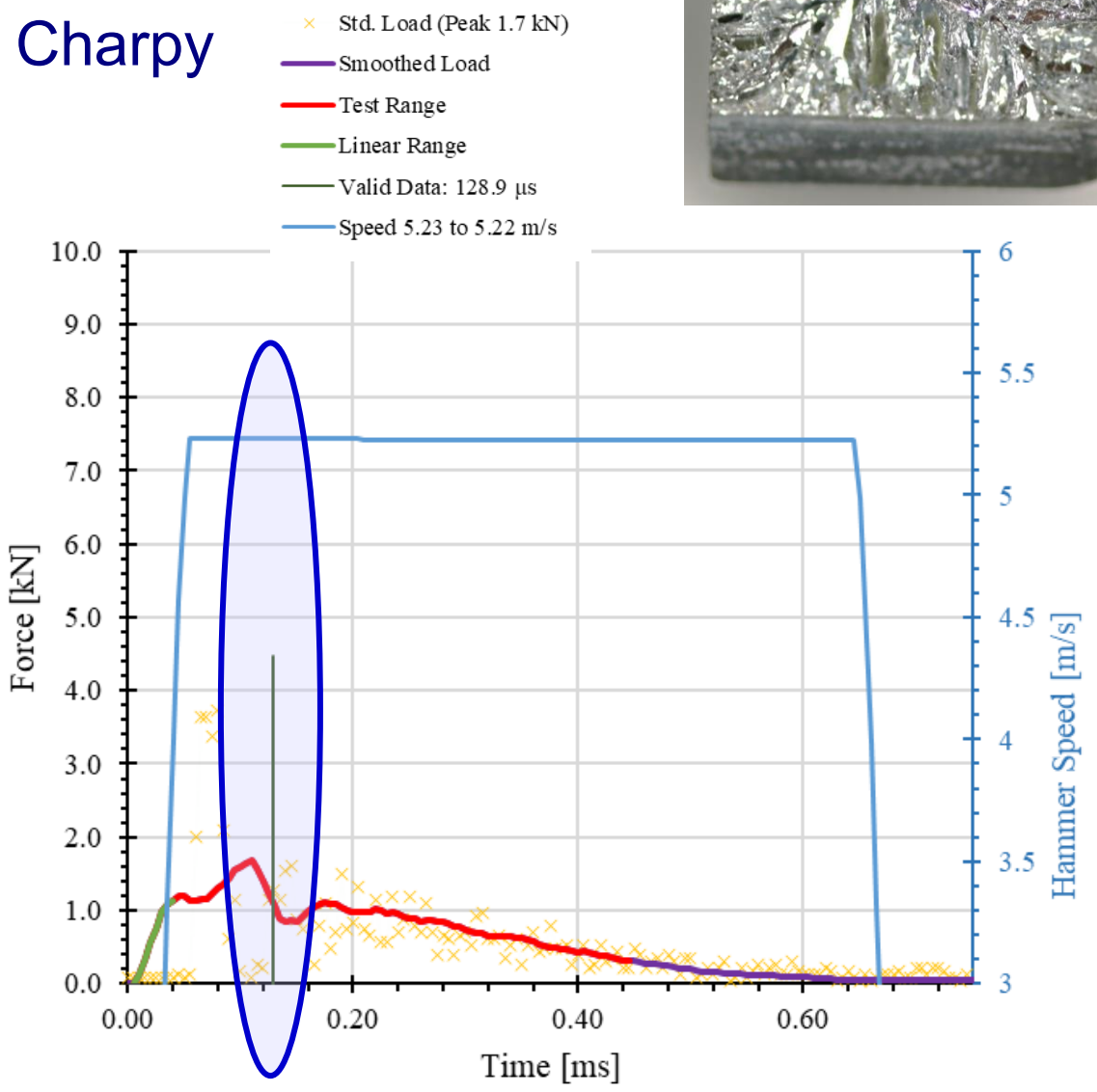
Data is comparable



Results

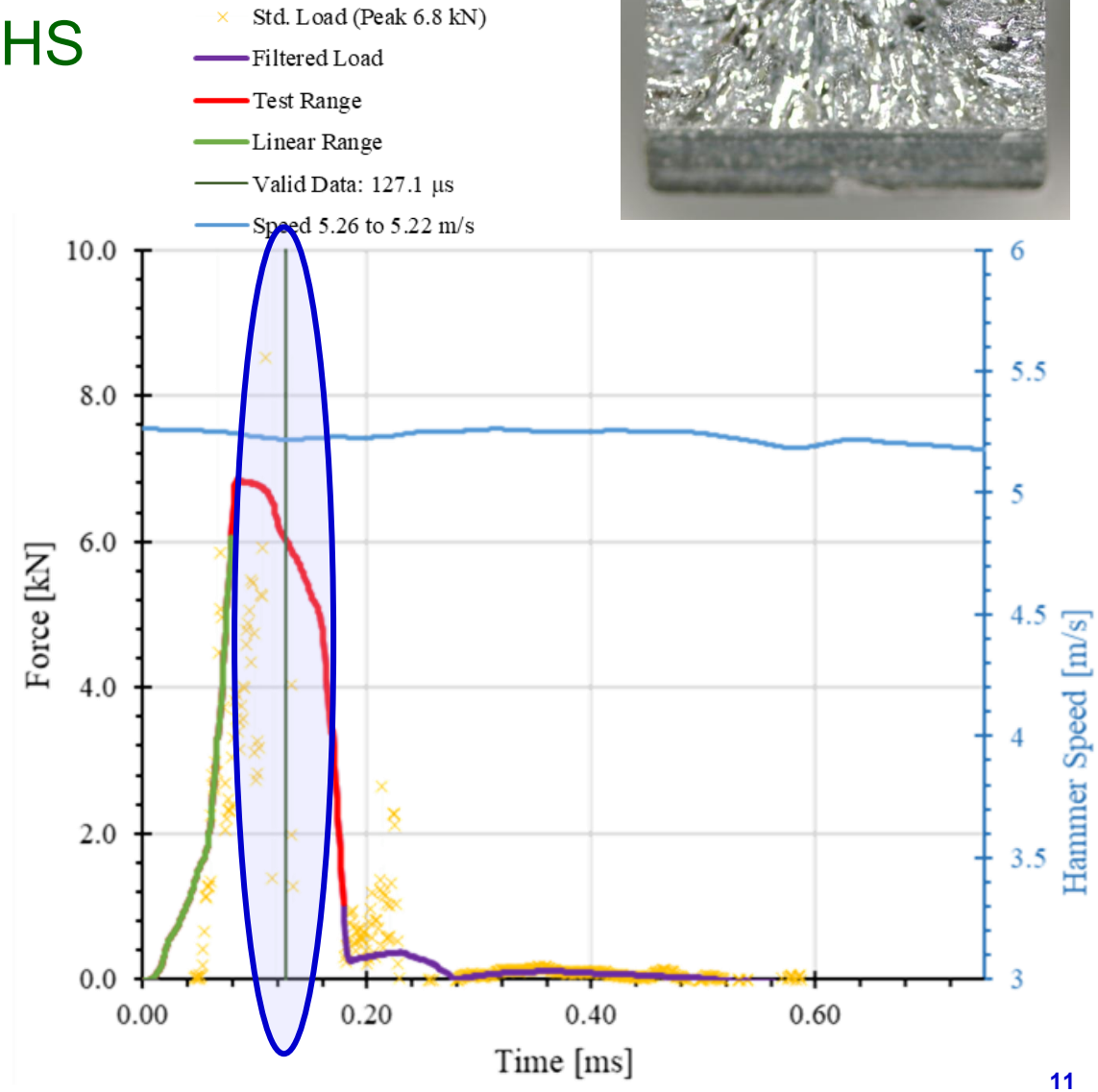
Zinc – Very Brittle

Charpy



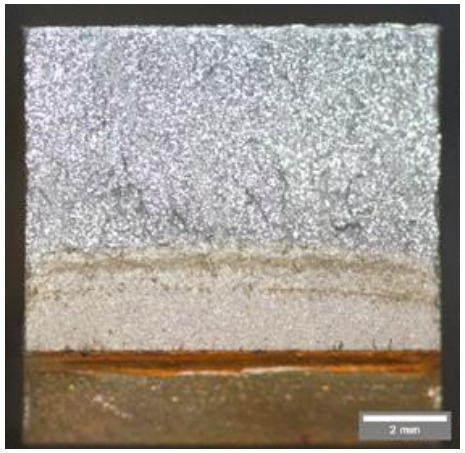
VHS

5mm



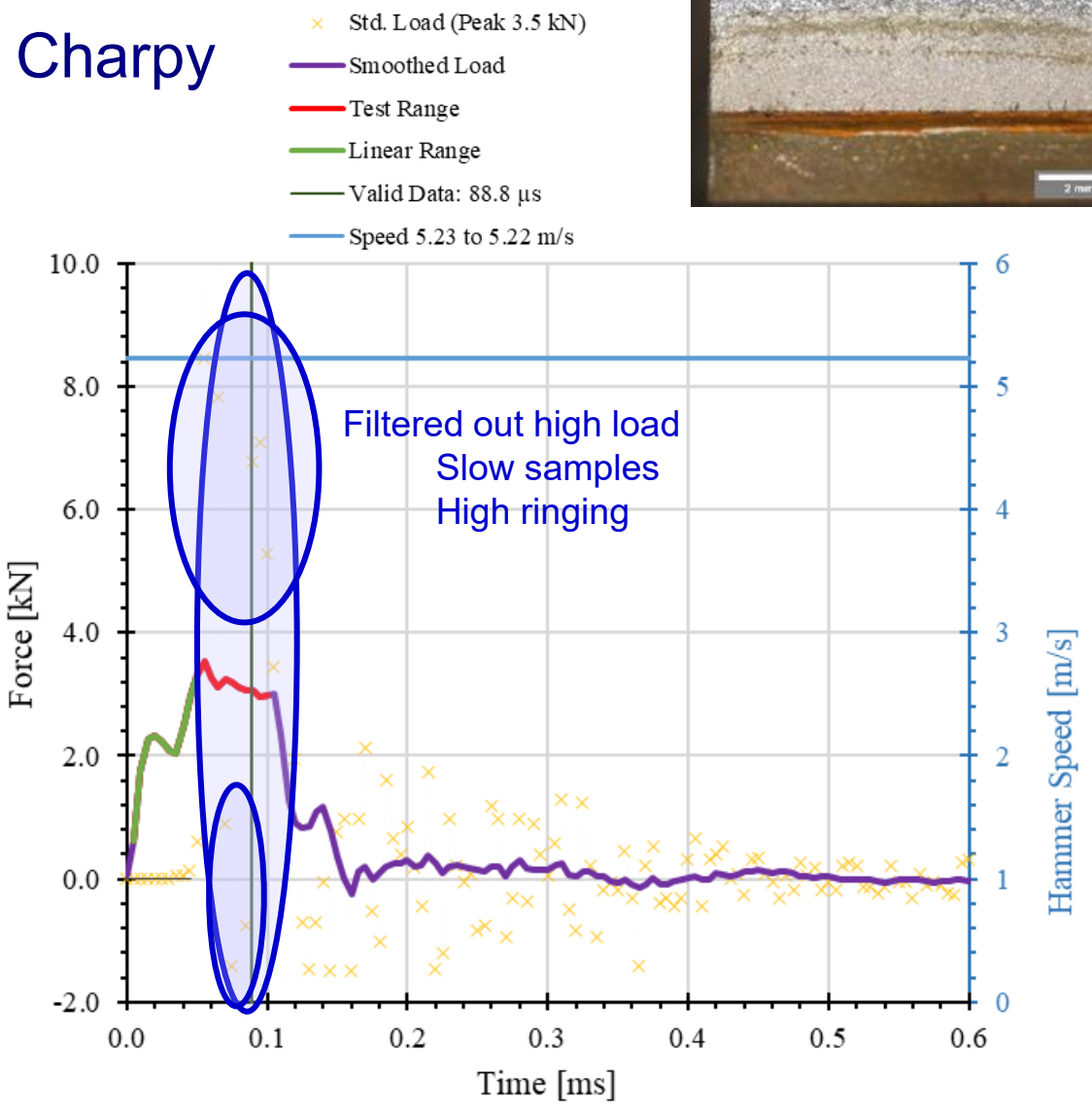
Results

Low Temp Steel – Very Brittle



5mm

Charpy



VHS

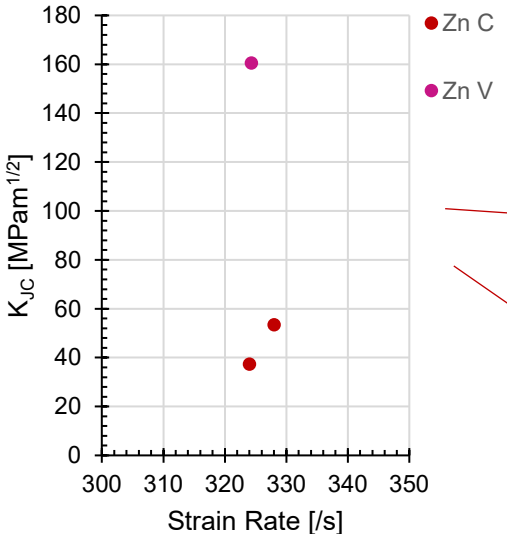
Zinc & Aluminium

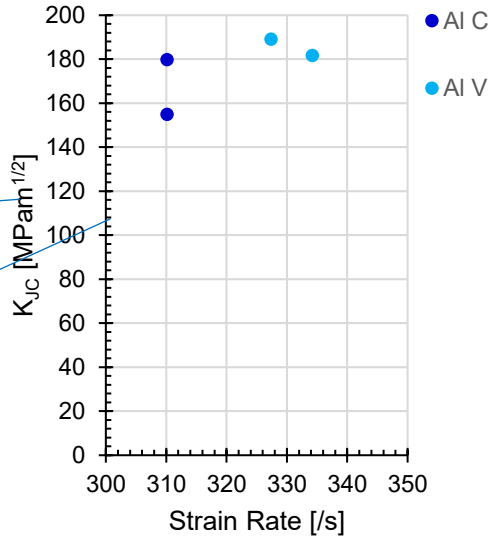
Brittle vs. Ductile
Charpy vs. VHS

Brittle Snaps too fast
Dynamically Invalid

Ave $\dot{\varepsilon}_0$:	327.8	/s		
Ave Δv:	0.08	m/s	±0.25	

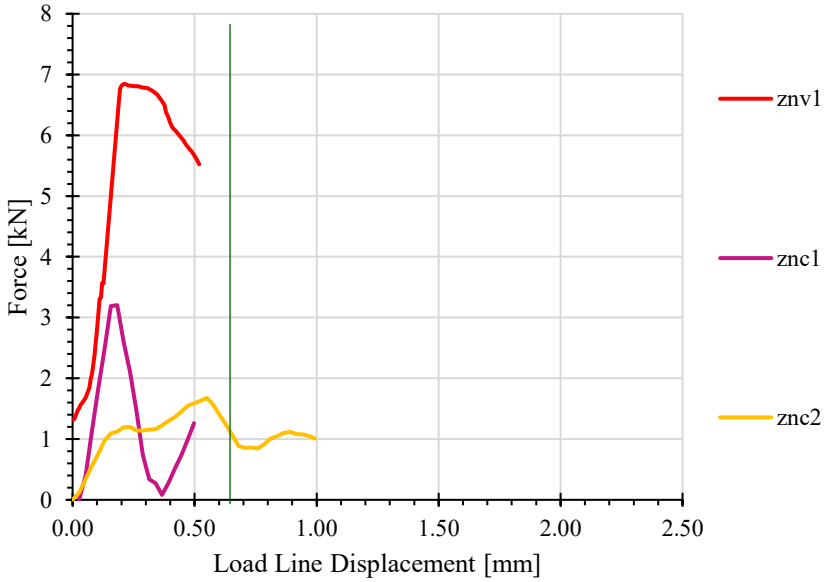
Similar strain rate on both machines

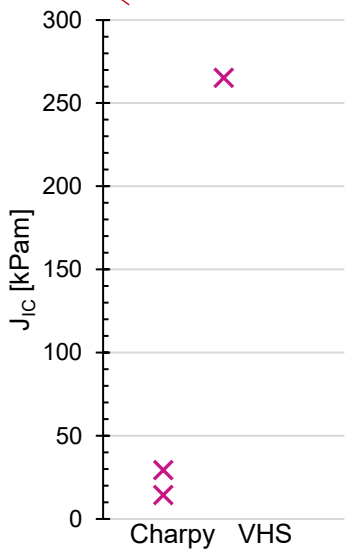


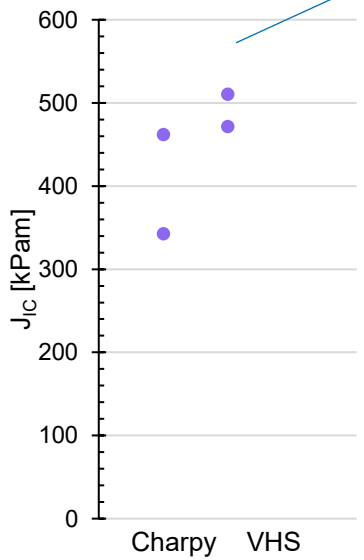


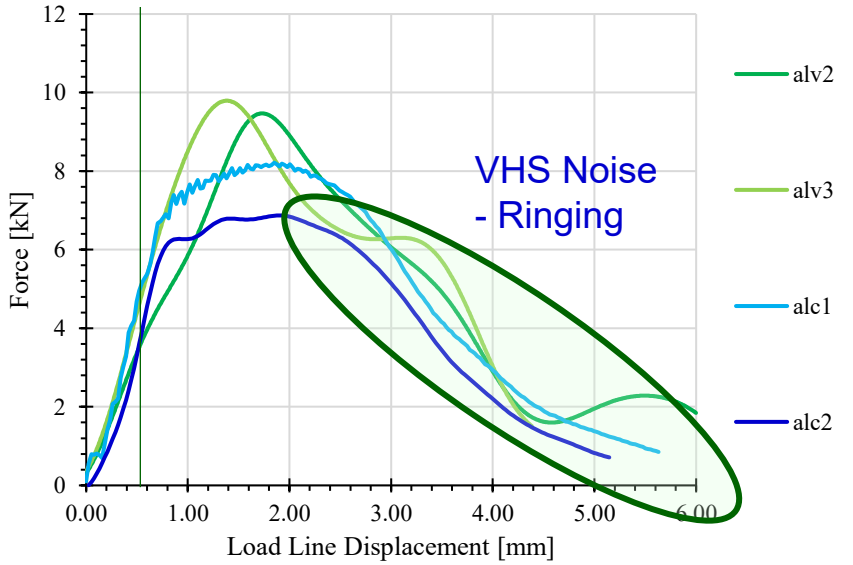
Big Difference in Brittle
CHARPY Slow Sample rate
VHS Initial Shock Ramp-up

Similar in Ductile
More time to sample and less effect by uncertain rise time









Conclusion

Both Function for Ductile

Brittle tests are all Dynamically invalid for Fracture

Both methods require **low stiffness ductile metal** to be effective. When too stiff…

- CHARPY looses highest loads from slow sampling
- VHS overloads from shock ringing

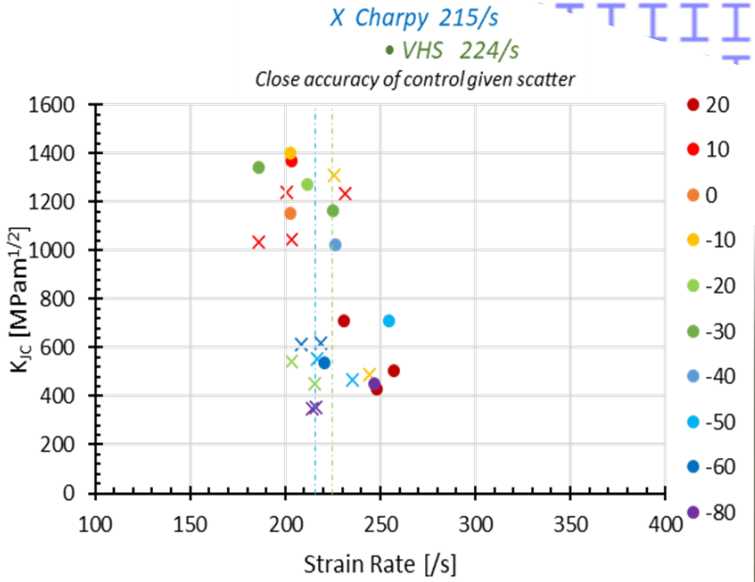
Smooth collapse makes end of test difficult to identify

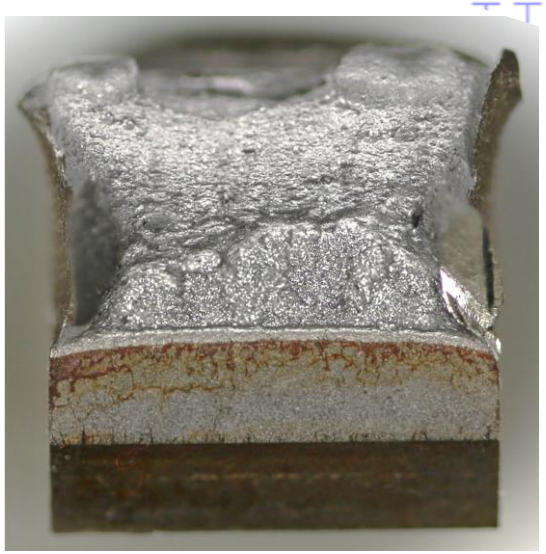
Good strain rate control

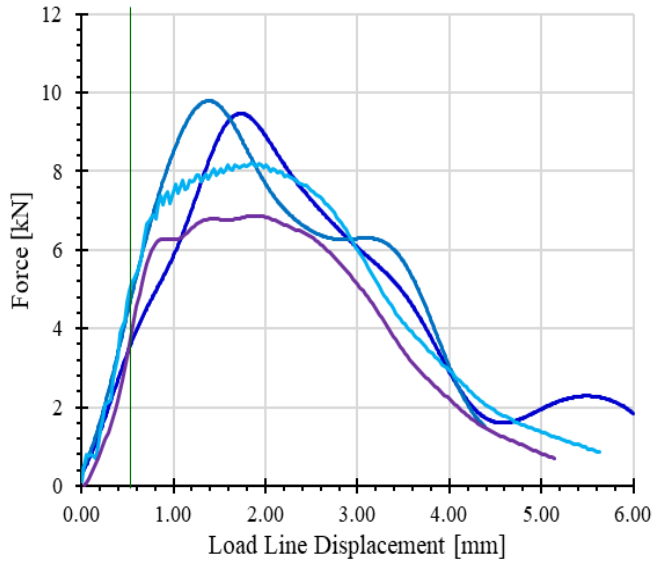
- Charpy has advantage of momentum and stiffness
- VHS system can be improved and tuned

Crack growth monitoring (norm. & linear) compare well

- Similar profiles with equal benefits and draw-backs







Conclusion

Effect of Fixed energy Input vs. Speed control testing

No observable difference

Rig rigidity and data acquisition lead to larger difference.

Next – Improve Procedures

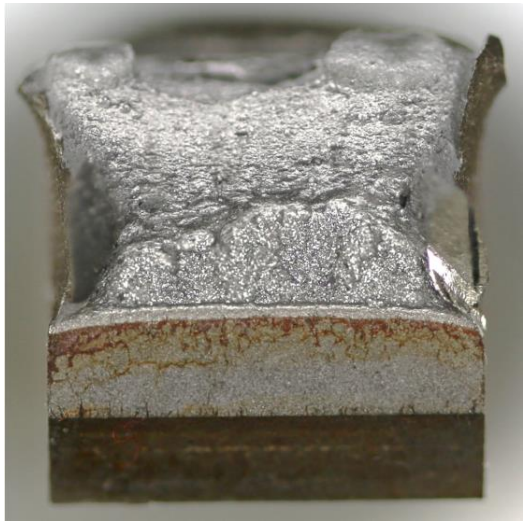
VHS – More ridged system to reduce ringing

Crack growth by Potential Drop

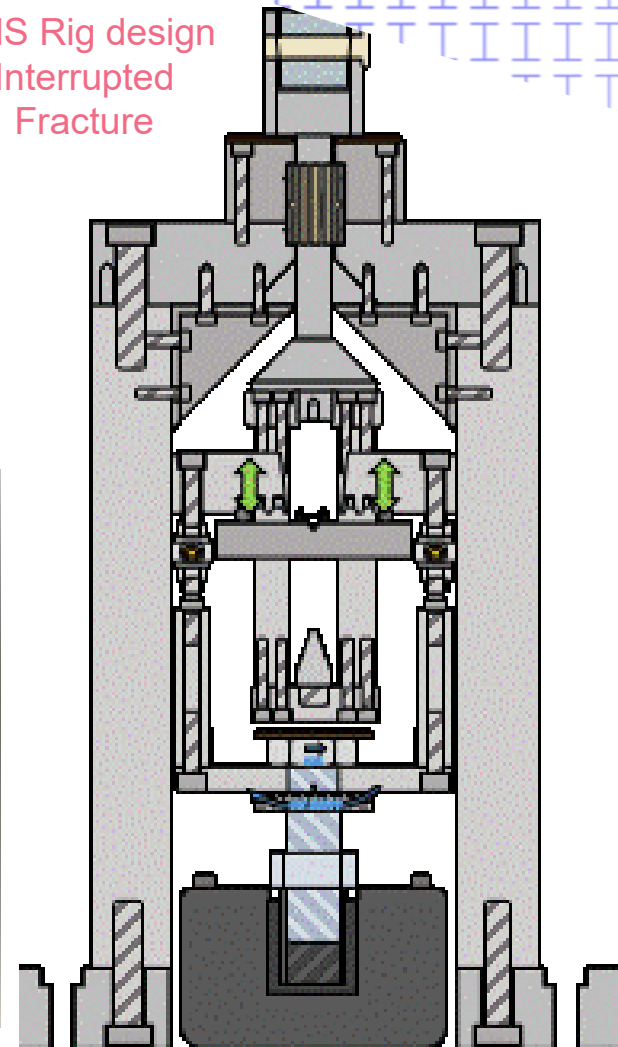
Next - Interrupted testing

Chapry ‘low-blow’

VHS – Novel test rig



VHS Rig design Interrupted Fracture



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