GREAT DESIGNS IN STEEL

NEW GENERATION OXIDATION RESISTANCE (COATING FREE) PRESS HARDENING STEEL

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General Motors

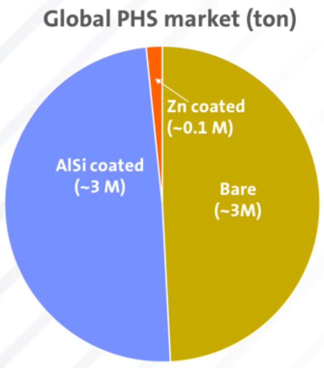
OUTLINE

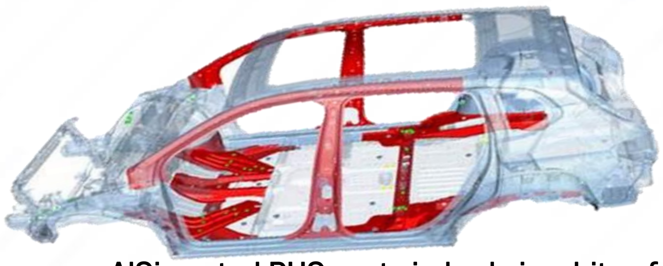
- Development Overview
- Component Bend Testing
- Developing a CAE Model
- Coating Adhesion and Welding Results
- Future Work
- Summary

DEVELOPMENT OVERVIEW

Background and problem statement, alloy chemistry inspiration, material properties and microstructure.

PHS OVERVIEW, MOTIVATION FOR NEW DEVELOPMENT



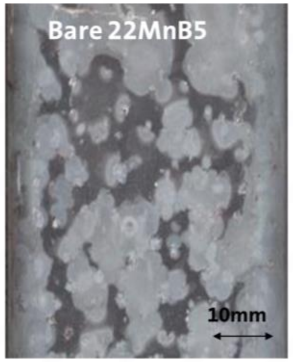
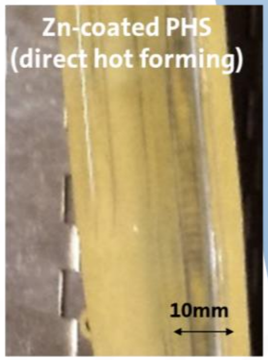


AlSi-coated PHS parts in body-in-white of Buick Envision: (~36 parts, >50 Kg)

PHS with ultra high strength (1500 MPa) are widely used for body structure applications since 1970s.

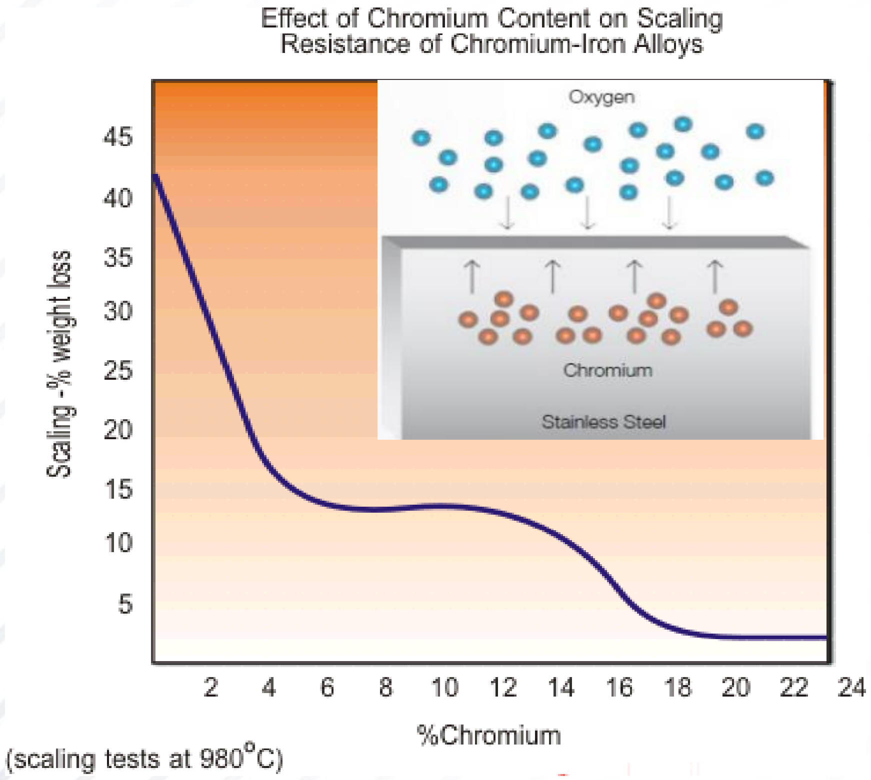
Current market share is AlSi coated and bare, with a small Zn coated component

A low cost, oxidation resistant steel is highly desired by automotive OEMs.

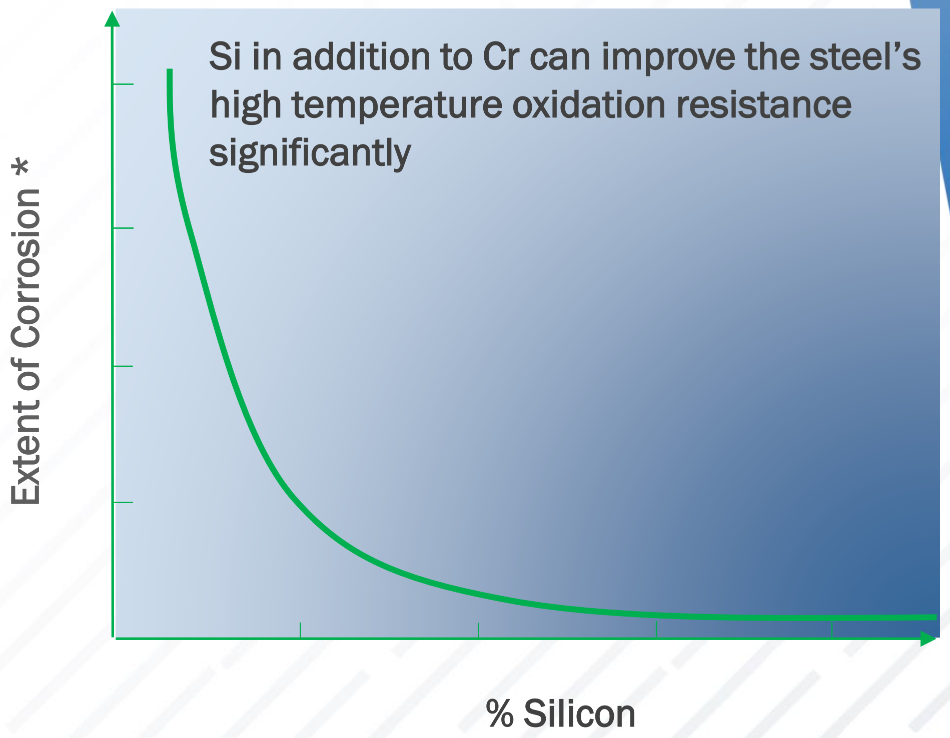
	Since 1970s	Since 1999	Since 2016
Surface condition after hot forming:			
Advantages & Drawbacks	Low cost but poor oxidation resistance (die cleaning and shot blasting needed)	Good oxidation resistance but high price and limited supply base (IP monopoly)	Limited galvanic protection, but narrow process (forming and welding) window, and still need shot blasting post forming

STAINLESS STEEL, BUT ONLY TEMPORARILY…

Uncoated stainless steel has life-time oxidation resistance since the addition of Cr (>12%).



Staying shiny and scale free at 930C for about 6 minutes needed for hot forming without pre-coating.



Example: For austenitic stainless steels, Cr18%&Ni8%
→ Life-time stainless at high cost

Coating free PHS: Cr+Si<=4% & 0%Ni
→ Short-term stainless at much lower cost

*A. S. Khanna ,**Introduction to High Temperature Oxidation and Corrosion**, page 123

NOVEL COATING FREE PHS: ALLOY COMPOSITION

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Considering all the requirements, the composition of coating free PHS is defined below (in wt.%):

Material	C	Mn	Cr+Si+Mo	Nb+Ti	B	Bal.
AlSi coated PHS (22MnB5)	0.19~0.25	≤1.4	≤1.0	≤0.12	0.0008-0.005	Fe
Martensitic Stainless Steel for Hot Stamping	0.05~0.15	≤1.0	Si<0.75;Cr=11-13	≤0.15	None	Fe
Coating free PHS (uncoated)	0.19~0.25	≤1.4	≤4.0	≤0.12	None	Fe

Carbon for strength, hardenability and weldability

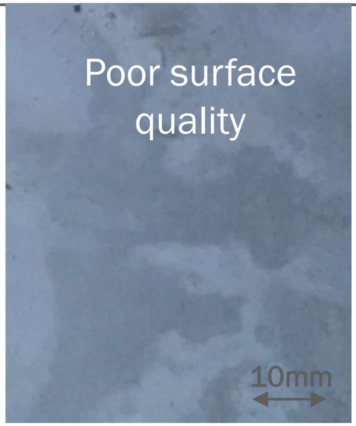
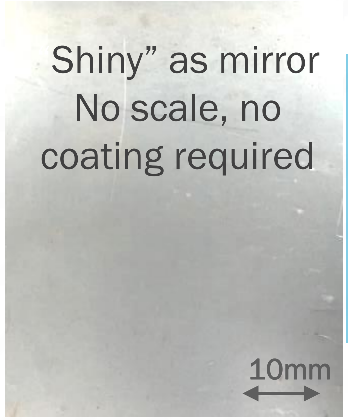
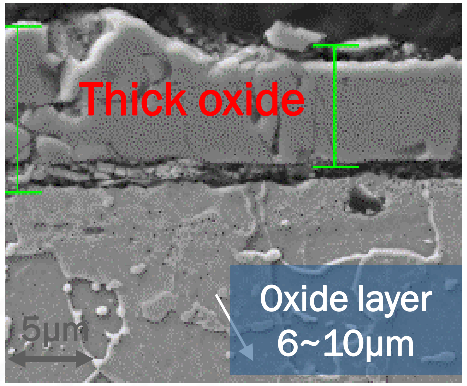
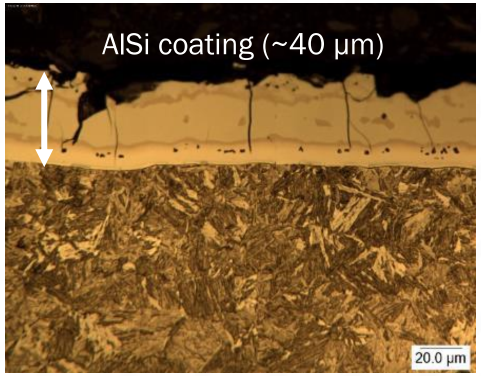
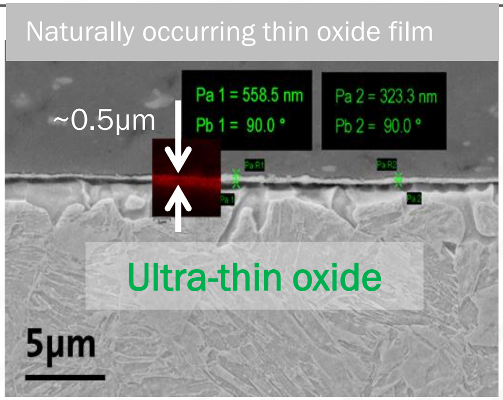
Mn to set austenitization temperature

Cr+Si for oxidation resistance & Cr for increased hardenability

Nb added for grain size control. No Ti needed.

Cr addition means B is unnecessary for hardenability

RESULTS: OXIDE THICKNESS AFTER HOT STAMPING

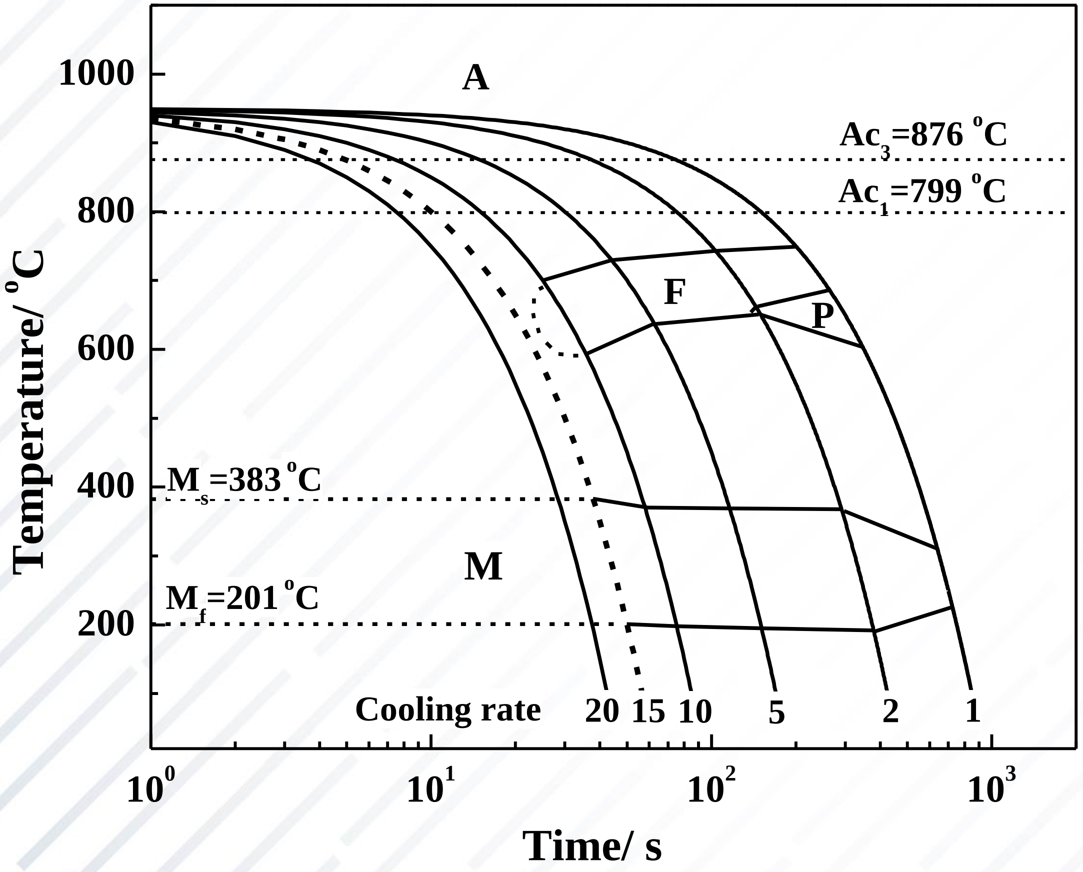
Material	Bare 22MnB5	AlSi Coated 22MnB5	Coating Free PHS
Surface condition			
Oxide/ coating morphology			
Advantages & Drawbacks	Low cost, Scale removal required	Good oxidation resistance, limited supply base	Good oxidation resistance NO SCALE REMOVAL

Same austenitization parameters are used for all three PHS.

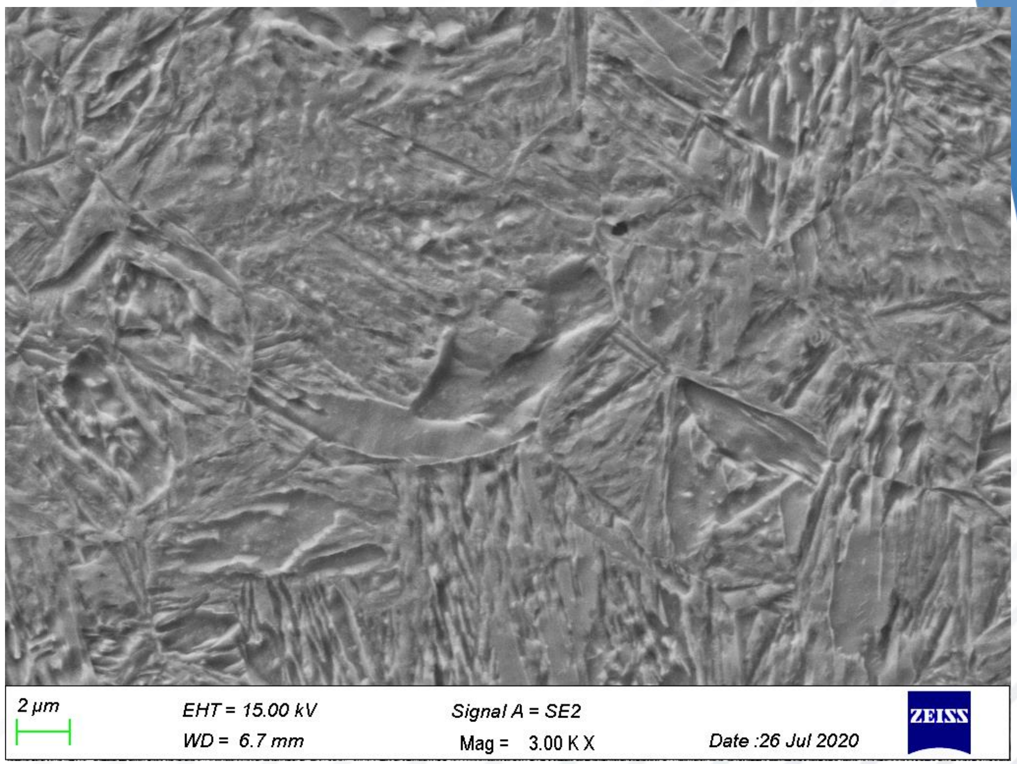
RESULTS: NO CHANGE TO PRODUCTION LINES REQUIRED

The critical cooling rate for coating free PHS to achieve complete martensitic transformation is 15 °C/s, compared to conventional 22MnB5 (~27 °C/s) for hot forming application.

CCT diagram

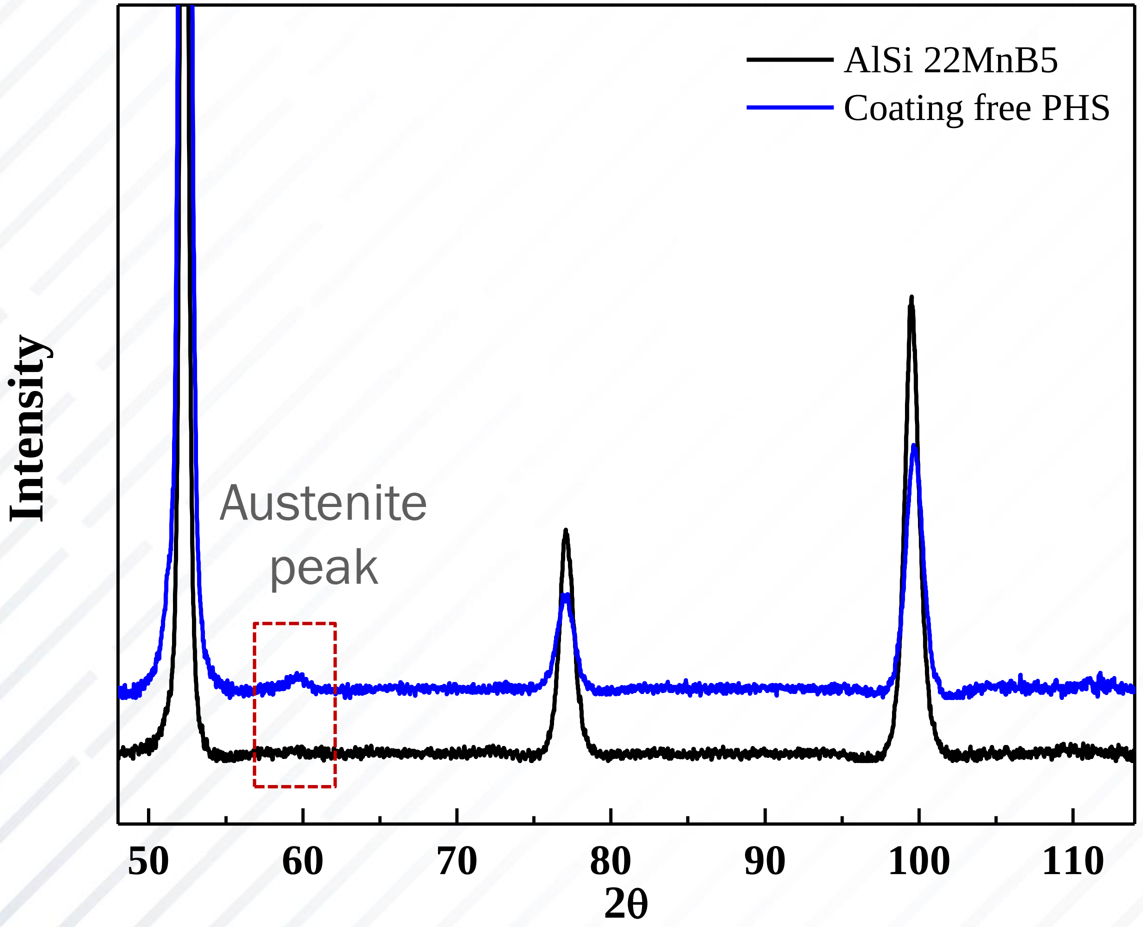


Microstructure after air cooling

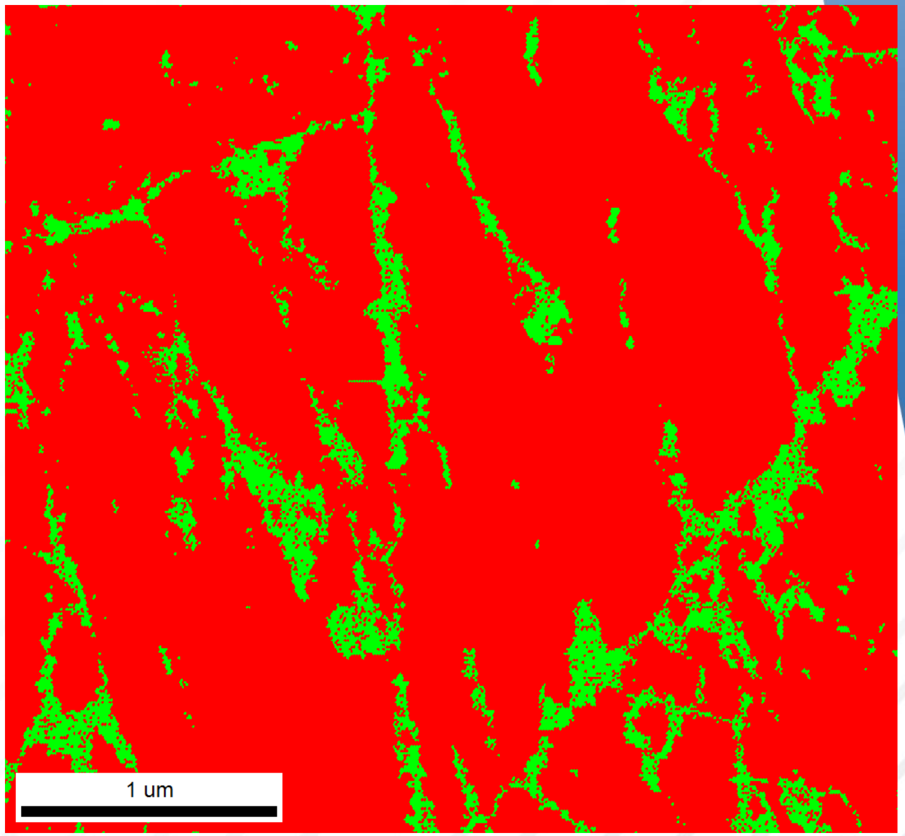


RETAINED AUSTENITE IN MICROSTRUCTURE

New alloy design enables the formation of beneficial retained austenite.



~5 vol% retained austenite



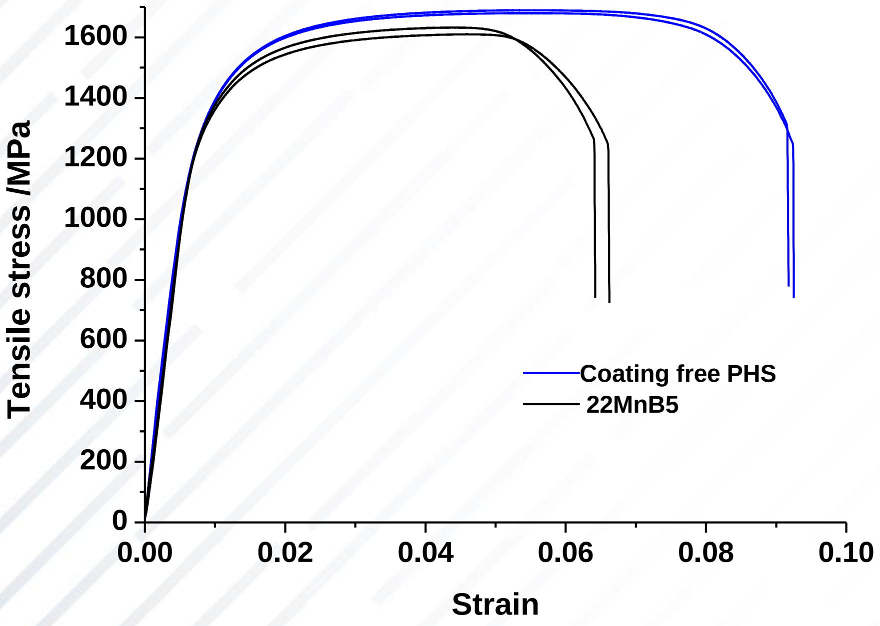
Retained austenite in green

COUPON TENSILE AND BENDING RESULTS

Refined PAGS and retained austenite enable excellent improvement in mechanical performance over 22MnB5.

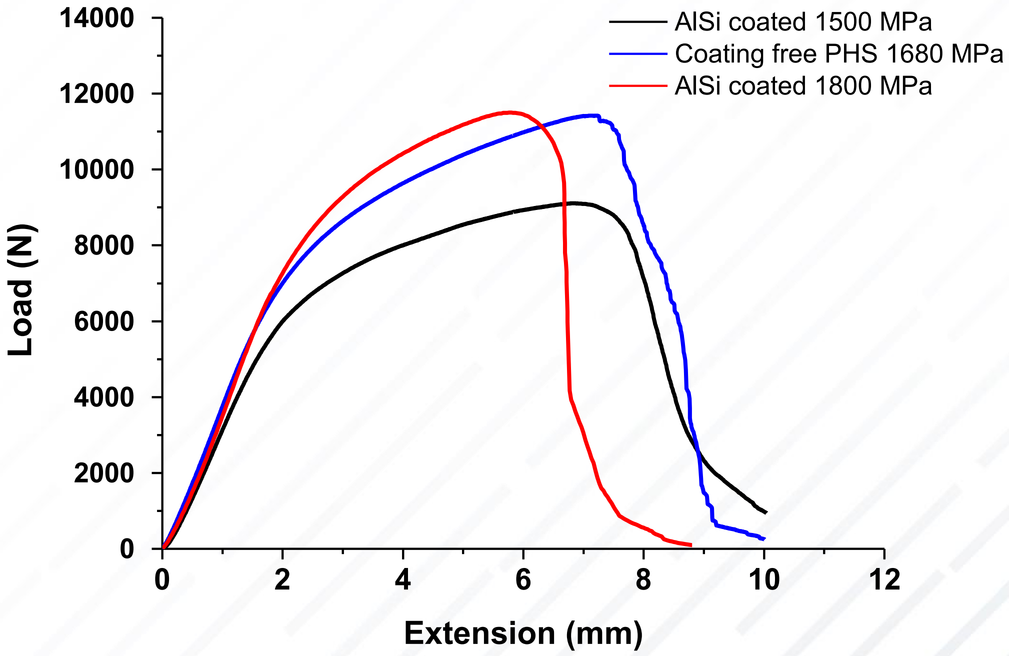
1.4mm thick PHS @ 920C/360S + paint bake

Uniaxial tensile



New PHS: 1680 MPa/9%
vs. 22MnB5 (1500MPa/7%)

VDA 238-100 3-pt bending



New PHS: similar bending performance vs AlSi coated PHS 1500 MPa; same peak force vs AlSi coated PHS 1800 MPa.

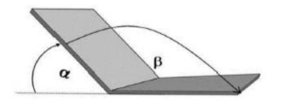


Fig. 2 Bending angle α (calculated at peak load or measured after unloading)

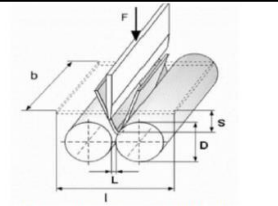


Fig. 1 Schematics of Bend Test

VISUAL SURFACE QUALITY POST HS BARE VS. UNCOATED

Coating free PHS has superior surface quality (still shiny) compared to bare PHS.
Both samples produced on the same production line with the same parameters.

Coating free PHS

Conventional bare PHS

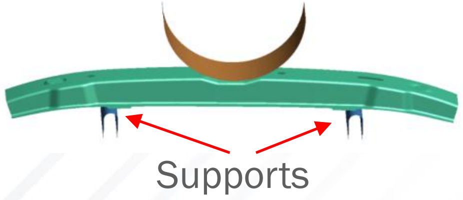
COMPONENT BEND TESTING

Characterization of energy absorption behavior.

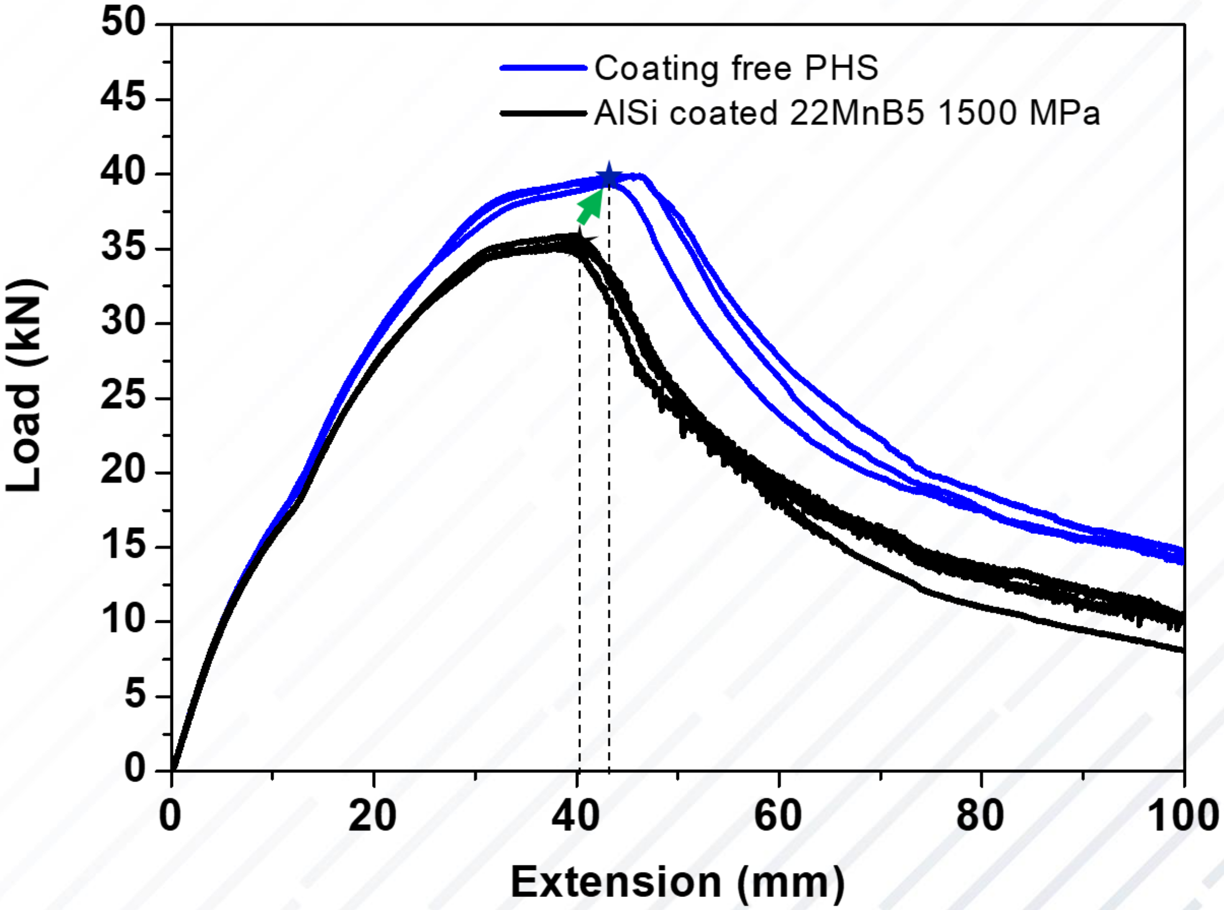
COMPONENT BENDING PERFORMANCE I:

COATING FREE VS 1500MPA ALSI

Coating free PHS has ~20% higher energy absorption (integration of load - displacement curve to peak force) compared to 1500MPa AlSi coated PHS.

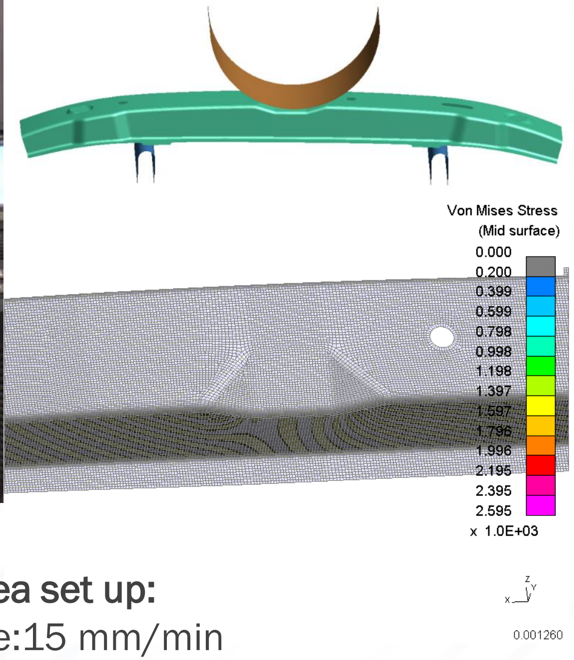


Loading rate:15 mm/min
Distance between supports: 550 mm
Both PHS baked at 170 ºC/20min

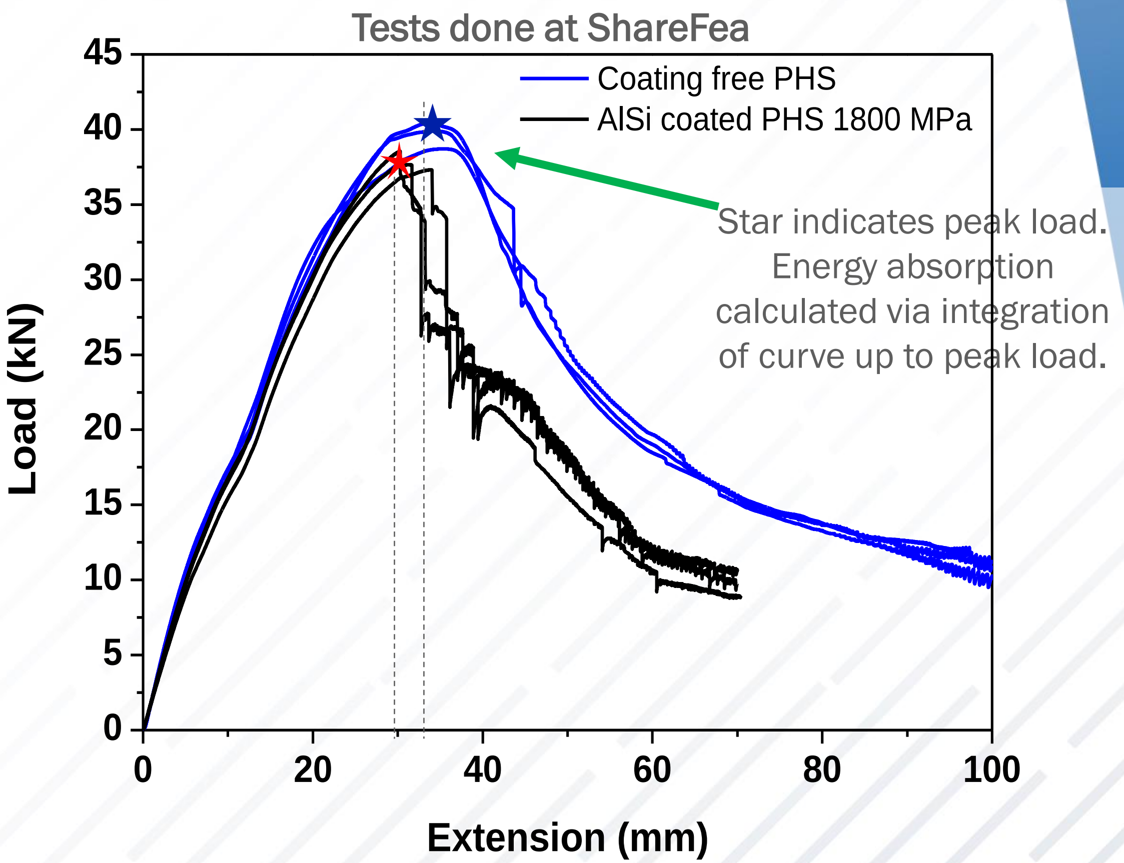


COMPONENT BENDING PERFORMANCE II

Coating free PHS has ~23% higher energy absorption (integration of peak force and peak force displacement) than AlSi coated PHS 1800



ShareFea set up:
Loading rate:15 mm/min
Thickness of both materials: 14mm.
Distance of two supports: 525 mm

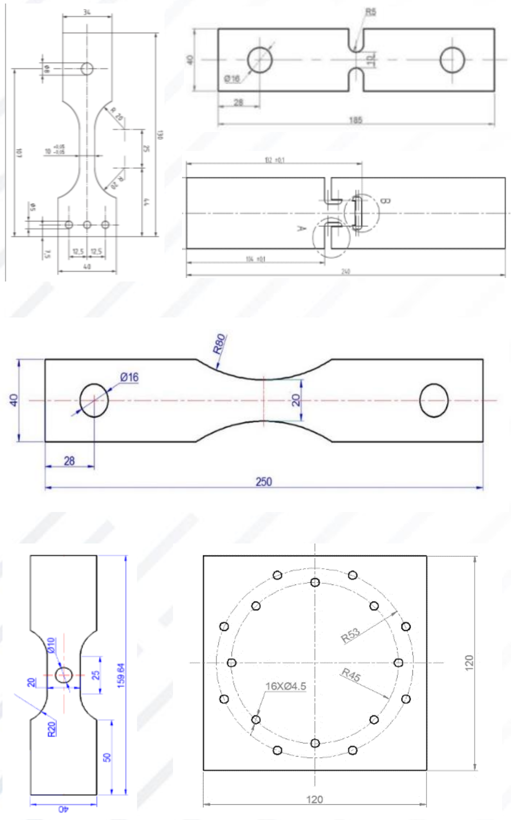


DEVELOPING A CAE MODEL

Correlating mechanical testing results to CAE simulation for material card development.

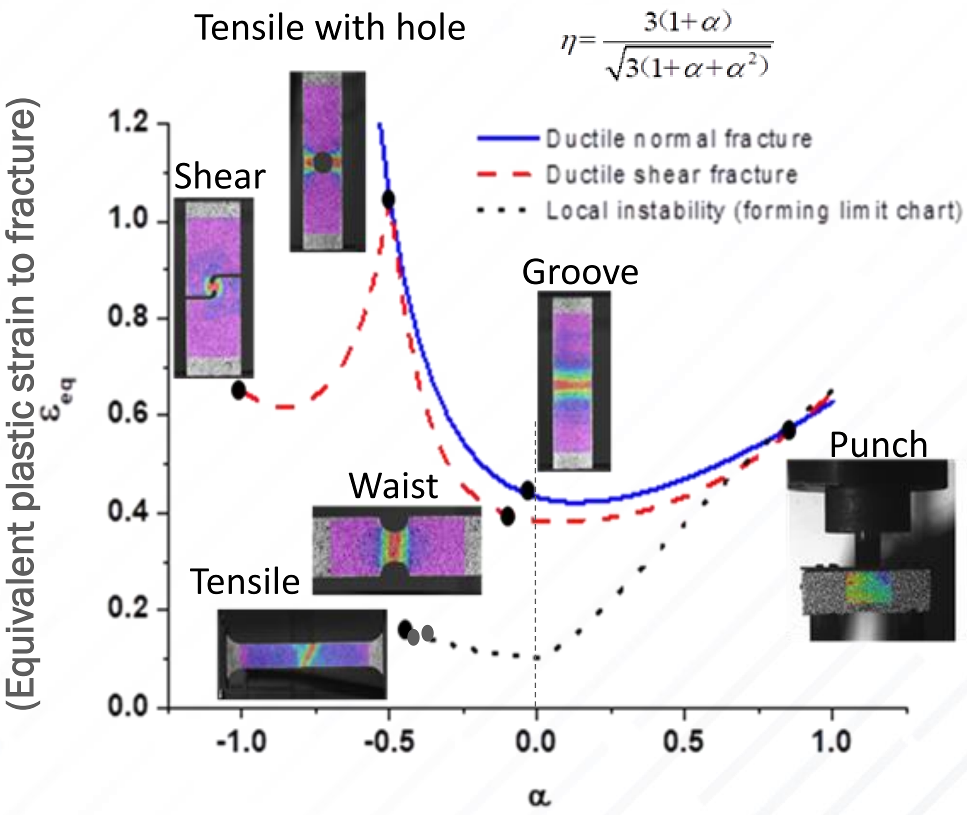
FRACTURE MODELING: TESTS USED TO BUILD MODEL

Coupon Tests



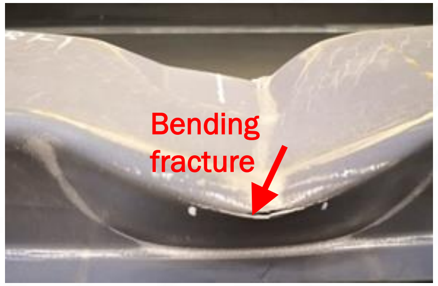
Fracture Locus (Input to CAE)

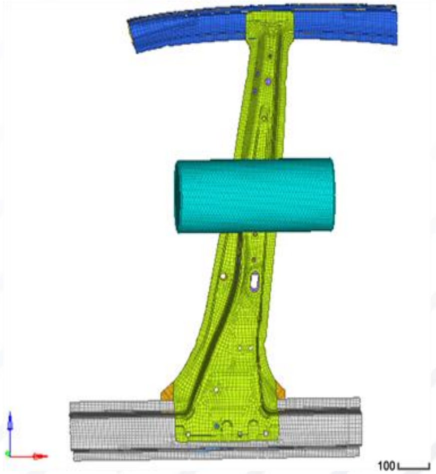
η: stress triaxiality



(Ratio of major true strain to minor true strain)

Quasi-static bending

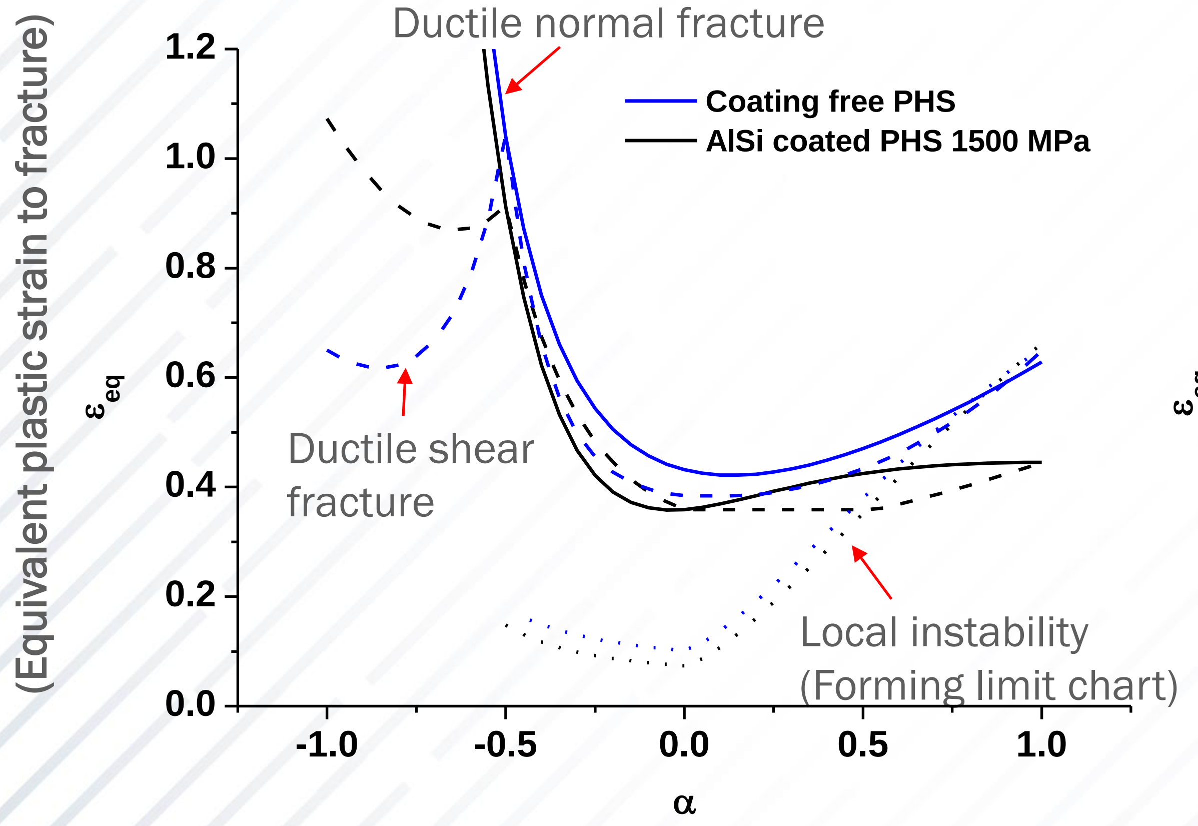


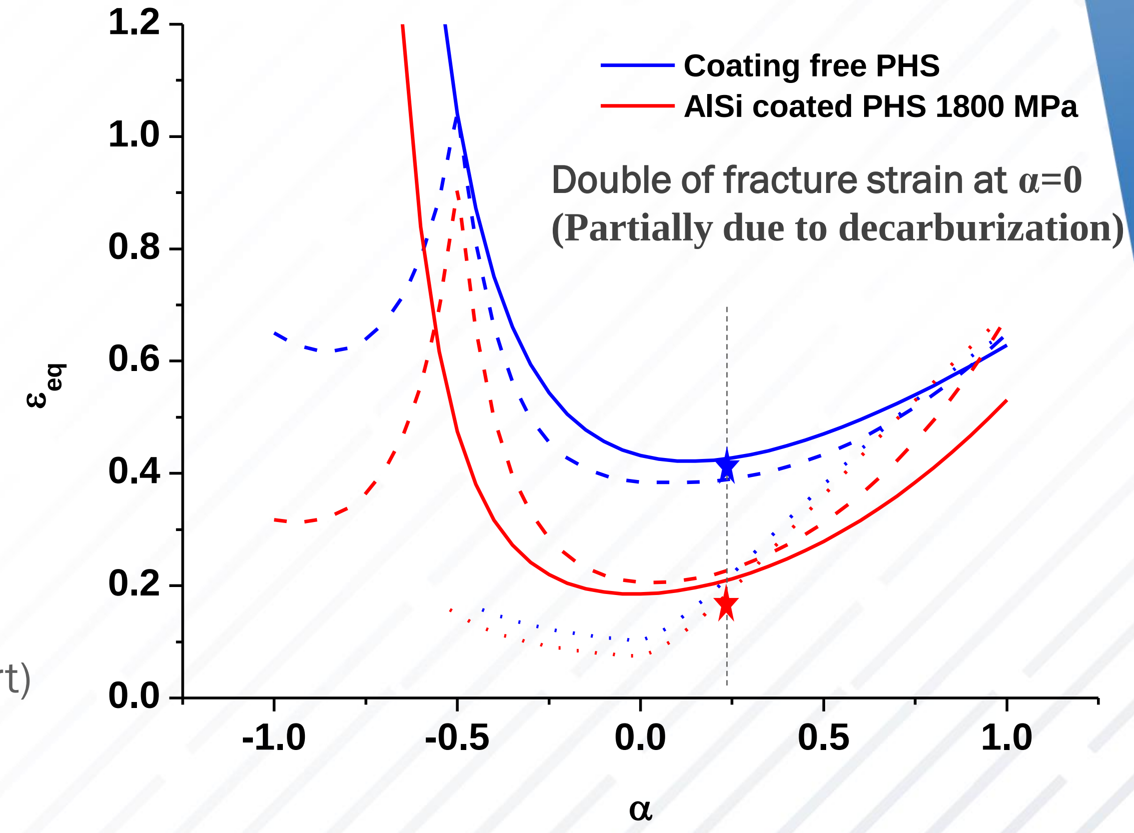


FRACTURE MODELING: FRACTURE LOCI (W CURVE) COMPARISON

Comparison of coating free PHS 1700 MPa, AlSi coated 1500 and 2000 MPa

Coating-free PHS has better fracture resistance than AlSi coated 1500 and 1800 MPa

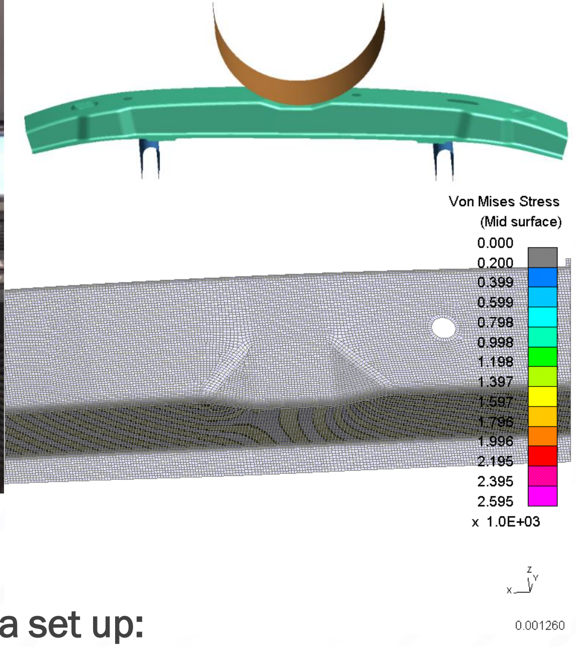


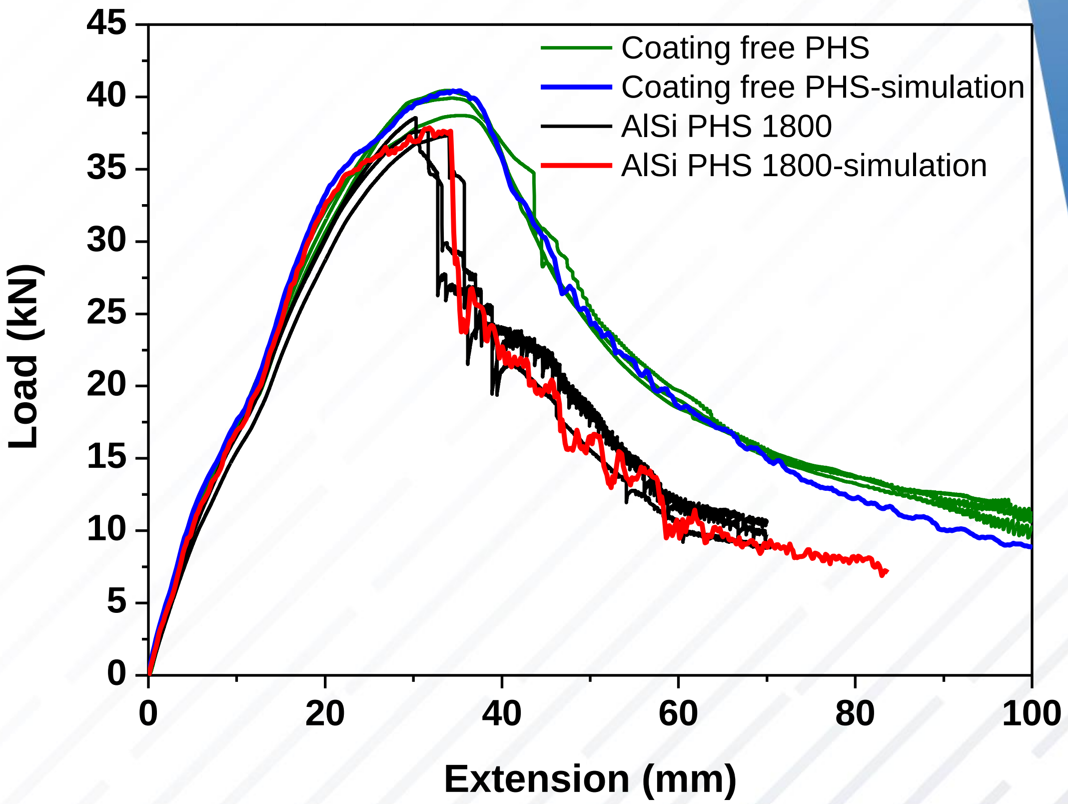


Ratio of major true strain to minor true strain

COMPONENT BENDING PERFORMANCE SIMULATION

Simulation accurately models the experimental results.





ShareFea set up:
Loading rate: 15 mm/min
The thickness of both materials is 1.4 mm.
Distance of two supports: 525 mm

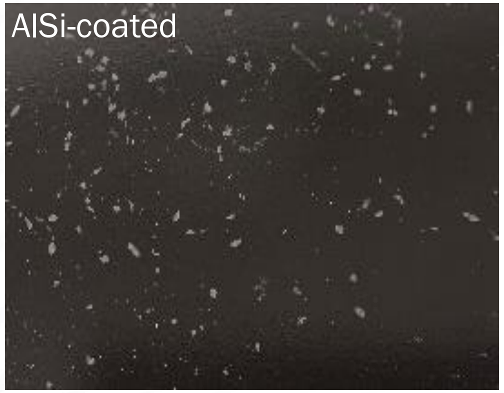
COATING ADHESION AND WELDING RESULTS

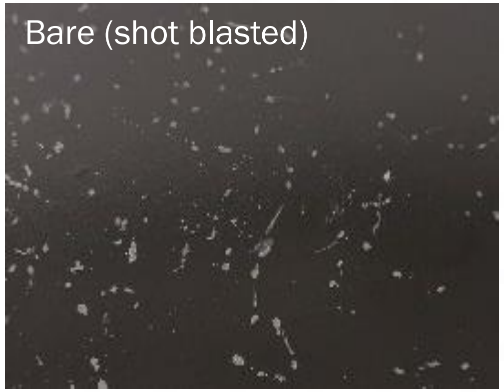
E-Coat adhesion results, welding schedule development (like to like) and cross tension/lap shear results.

RESULTS- PRELIMINARY E-COAT ADHESION ASSESSMENT

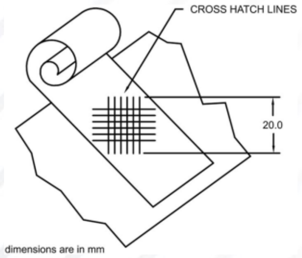
Hot stamping at 920 °C/360s +Phosphating + E-coating

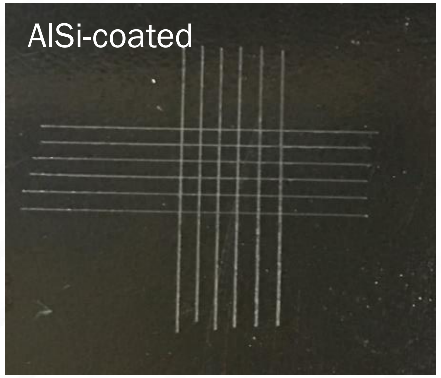
- Stone chip test (GMW 14700): AlSi coated PHS = Bare PHS = Coating free PHS

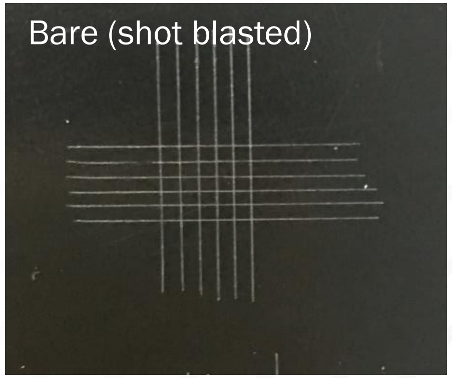


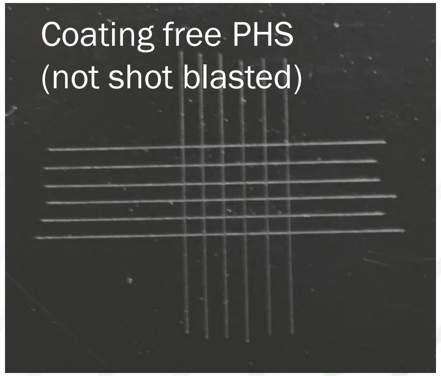


- Tape adhesion test (GMW 14829): AlSi coated PHS = Bare PHS = Coating free PHS







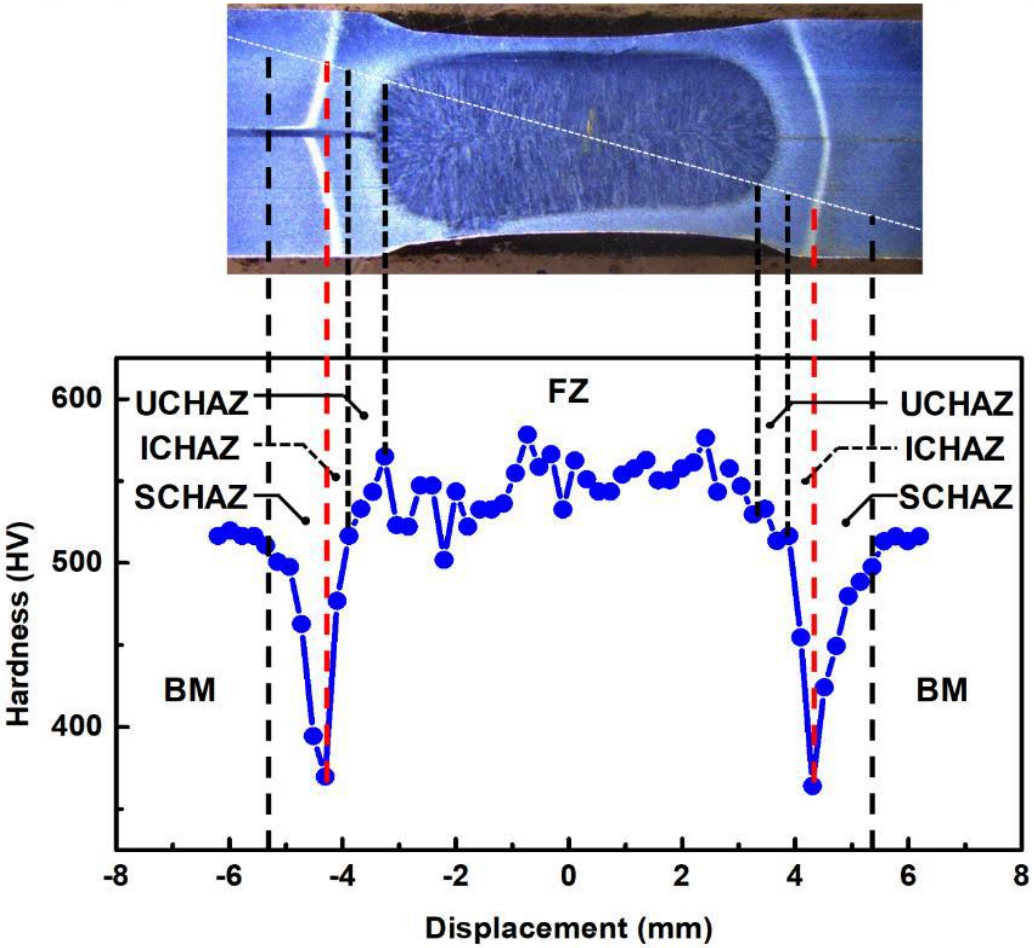


Good E-coating adhesion of Coating free PHS.

CROSS TENSION NUGGET EXAMPLE

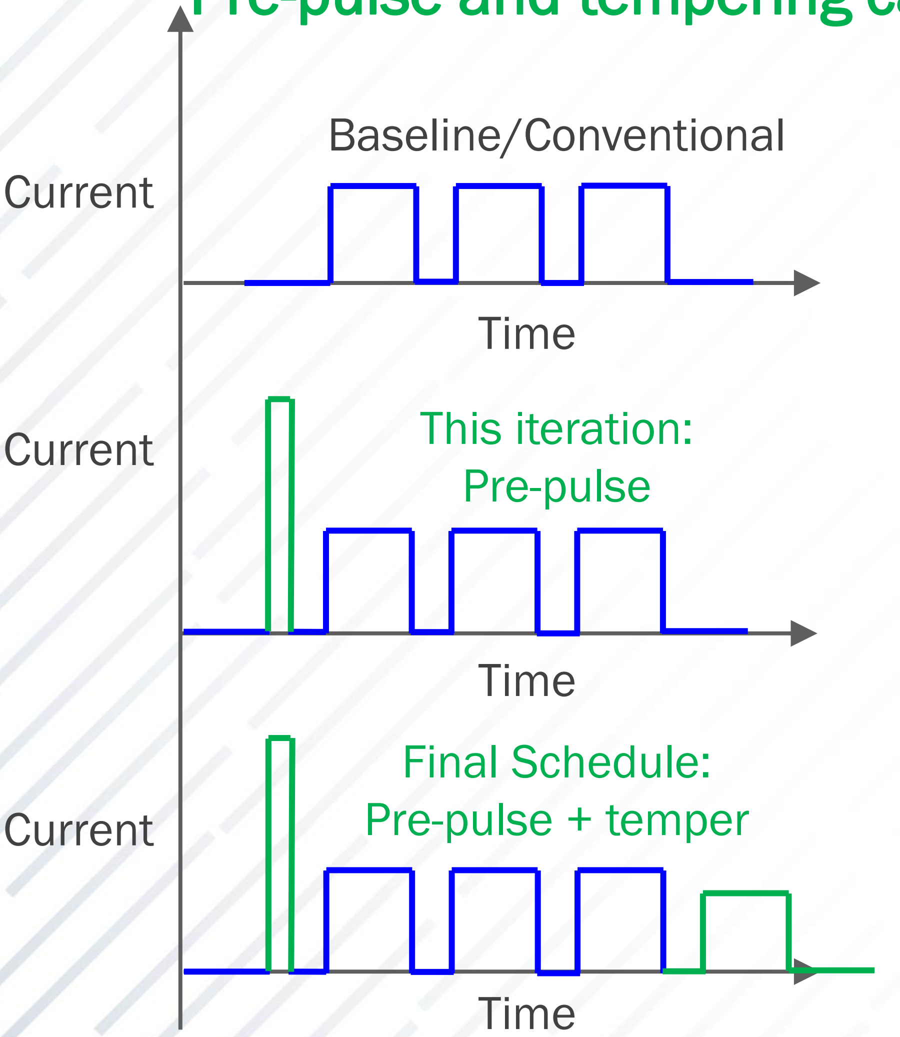
The hardness of the fusion zone is higher than that of AlSi coated 22MnB5.
Additional tempering pulses could be useful.

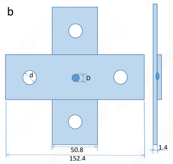
Welding parameters:
Force: 5kN
Current:
5.5/6.5/7.5kA
Weld time: 12ms*3



RSW: PHS TO PHS SCHEDULE DEVELOPMENT

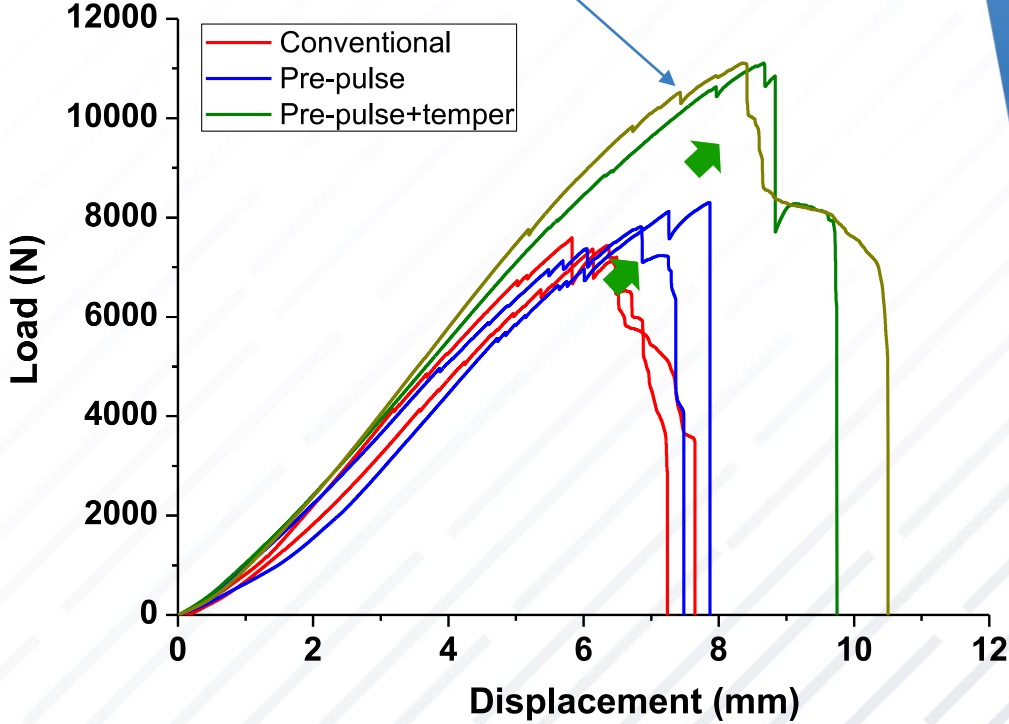
Pre-pulse and tempering can effectively improve the cross tension strength.





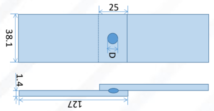
Cross tension performance

Peak load is the same with 2.0 mm AlSi coated PHS

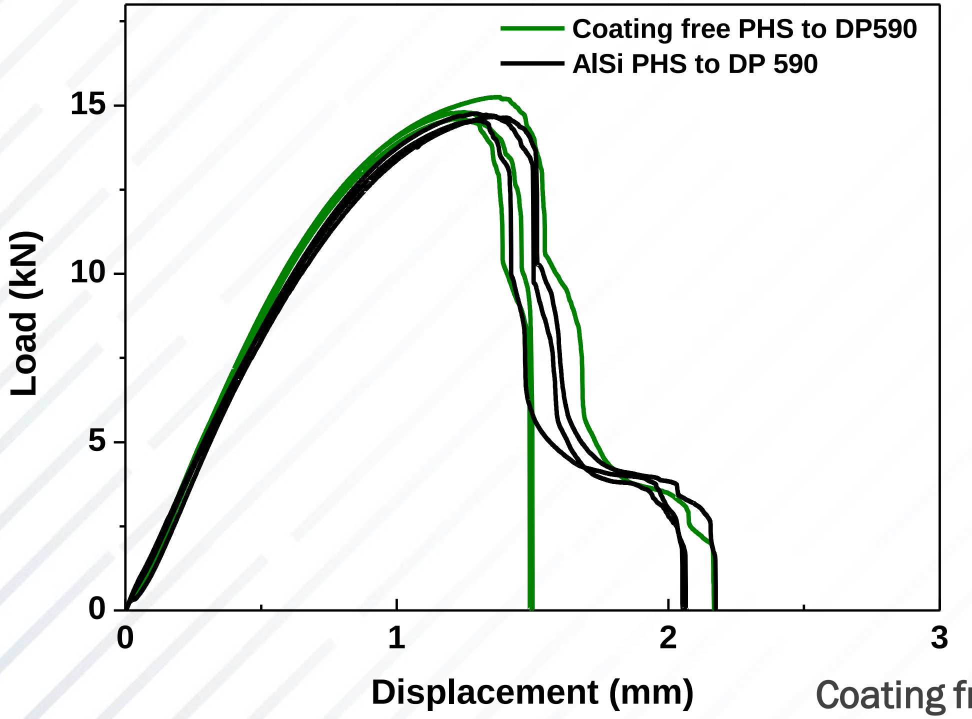


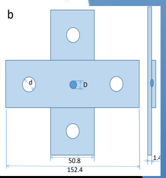
WELDING: PHS TO DP590

Same performance with existing AlSi coated PHS with the same stack up.

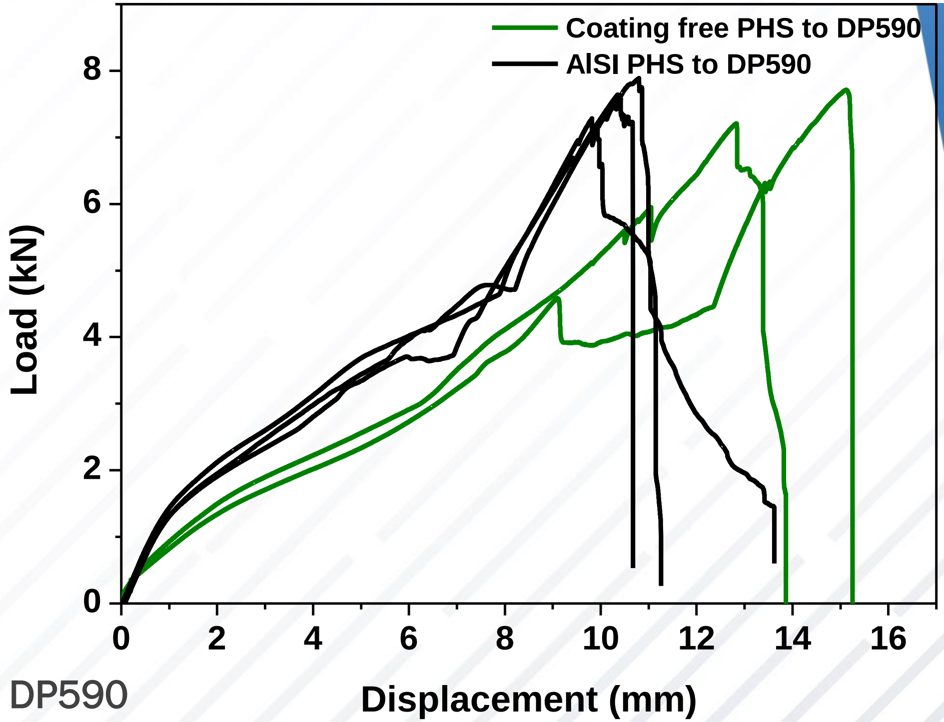


Lap shear test





Cross tension test



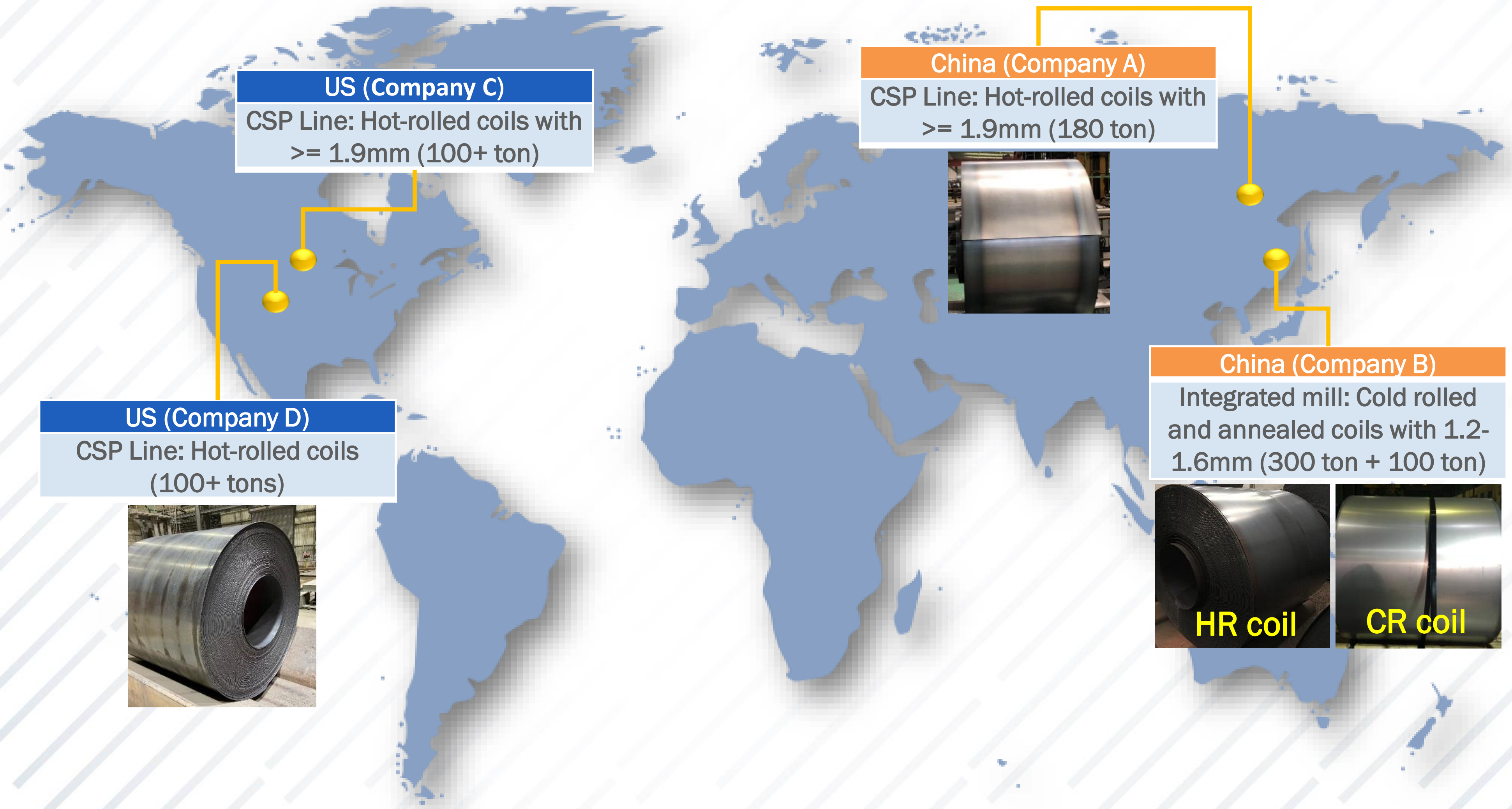
Coating free PHS (2mm) to DP590 (1.2mm) using existing schedule

FUTURE WORK

Commercialization update, new grade development, potential application projects.

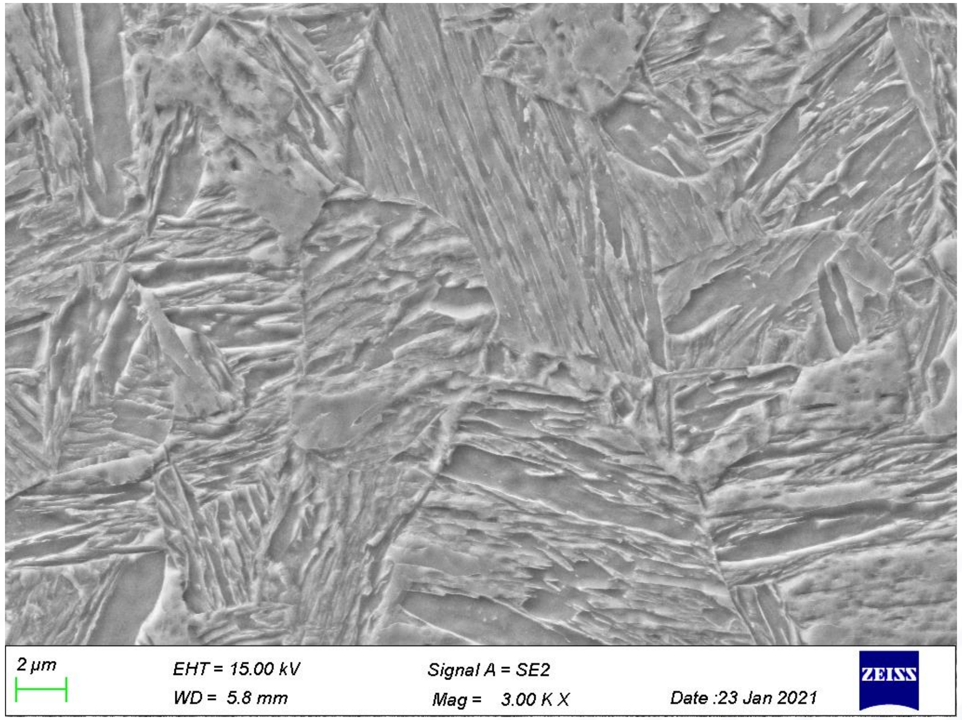
STEEL PRODUCTION TRIALS

Coating free PHS successfully produced via conventional steel making processes.



UPCOMING WORK: 1200MPA COATING FREE PHS

Fully martensite microstructure, same oxide layer protection in the furnace.

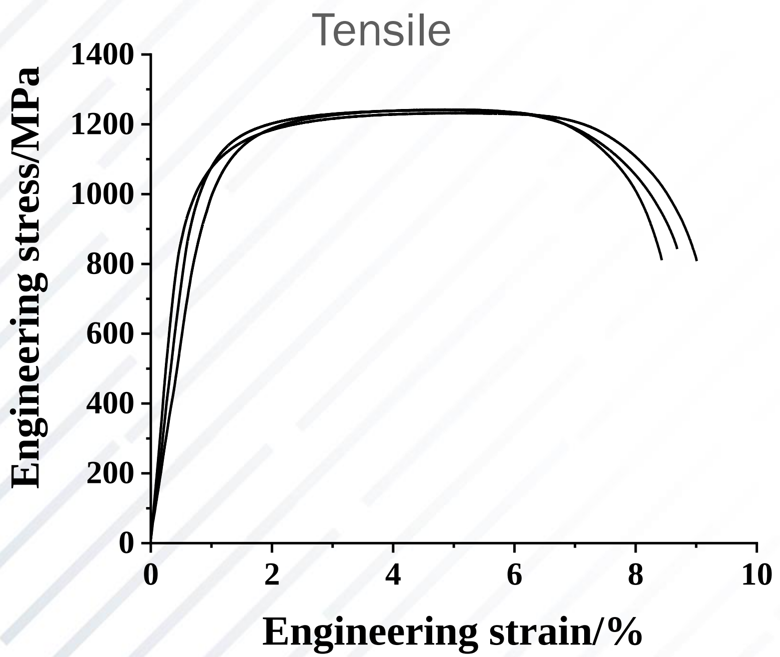


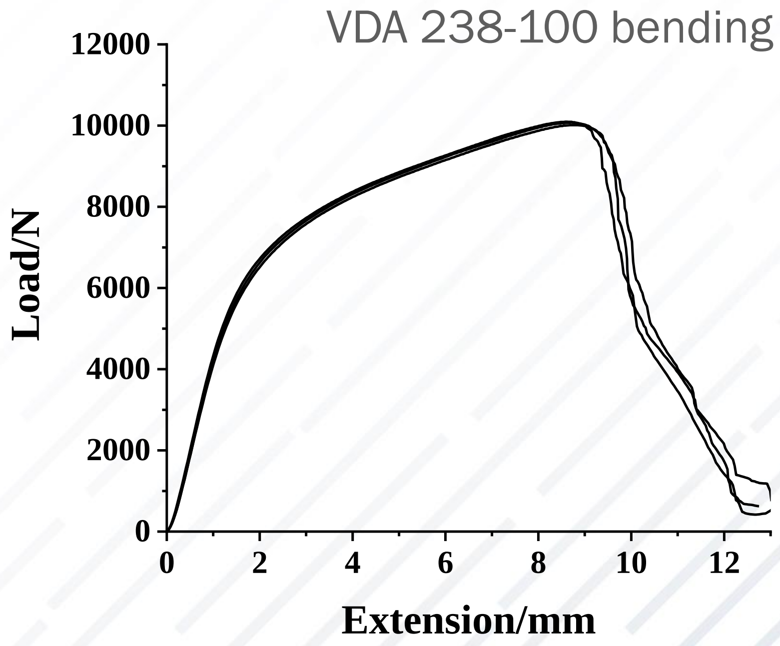
In wt.%	C	Mn	Cr+Si+Mo	Nb+Ti	B	Bal.
Coating free PHS (1700 MPa)	0.19~0.25	≤1.4	≤4.0	≤0.12	None	Fe
Coating free PHS (1200 MPa)	0.06-0.12	≤2	≤4.0	≤0.12	None	Fe

UPCOMING WORK: 1200MPA COATING FREE PHS

Excellent tensile and VDA 238-100 bending performance.

Steel	YS/MPa	UTS/MPa	TEL/%	UEL/%	Bending angle/°C	Peak force/N
Coating free 1200MPa (1.5mm)	1028±21	1237±4	8.4±0.5	4.8±0.2	76.5±0.6	10060±35
AlSi PHS 1200 MPa (1.5mm)	850	1080	6.0-7.0	4.5	80	N/A





FUTURE APPLICATIONS OUTLOOK

Hybrid material applications for broader industry adoption

	B-Pillar 	Door Ring 	Process
Existing AlSi coated PHS	1500 MPa + 500/1000 MPa	1500 MPa + 500/1000 MPa	**AlSi coated PHS:** Laser ablation + laser welding or filler wire +laser welding
Coating free PHS	1700 MPa+ 1200 MPa	1700 MPa+ 1200 MPa	**Coating free PHS:** Direct laser welding

SUMMARY

- New alloy development with Cr and Si additions allow for higher hardenability and, Cr specifically, develop a stable oxide layer in the furnace to protect from decarburization
- The improved chemistry allows for the presence of RA in the material, increasing the energy absorption in intrusion testing.
- Coating adhesion is not impacted by the stable oxide layer
- Welding results show promise with improved lap shear strength. Schedule development includes pre-pulse to break oxide and post pulse for tempering weld.
- Future work to come includes expansion of supply chain into the NA market, new 1200MPa grade and investigations into TWB for B-pillar and door ring components.

Thanks for your attention!

FOR MORE INFORMATION

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