GREAT DESIGNS IN STEEL

TWENTY YEARS

LASER WELDED COATING FREE PRESS HARDENED STEEL

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OUTLINE

- CFPHS Overview and Update
- Laser Welding- CFPHS to CFPHS
- Tensile Samples
- Tensile Results
- Laser Welded Impact Testing Results from China Science Lab
- Summary

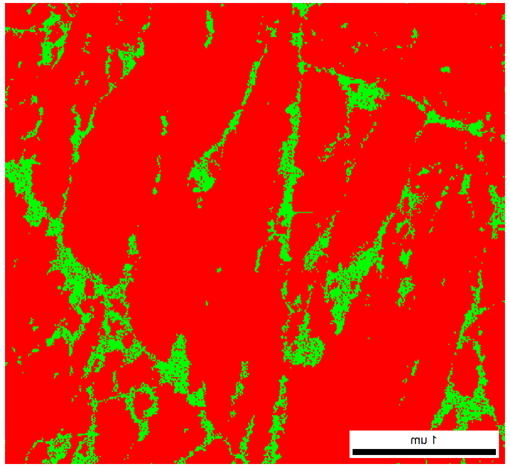
CFPHS OVERVIEW AND UPDATE

- Material Background, Microstructure and Tensile Properties
- Manufacturability and Surface Quality
- Project Updates and Future Work

INNOVATIVE MICROSTRUCTURE ENABLES INCREASED STRENGTH LEVELS

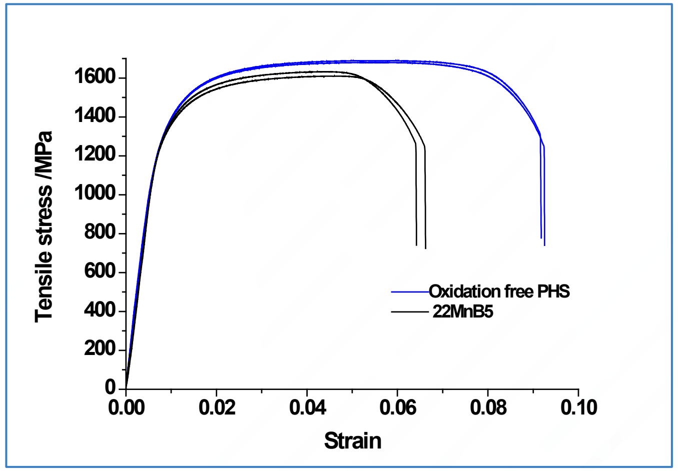
- The microstructure of CFPHS includes retained austenite (RA).
- RA transforms to martensite upon deformation, enabling increased ductility and toughness.
- The material can absorb more energy than traditional PHS, enabling a reduction in mass used for the same level of passenger protection.

Microstructure



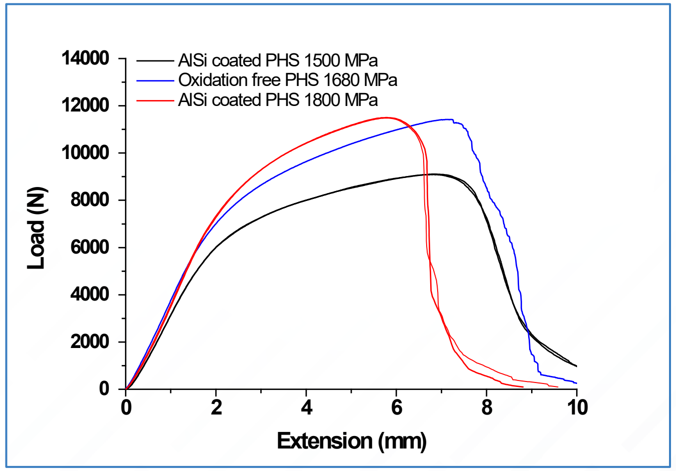
Retained Austenite in Green, Martensite in Red

Uniaxial Tensile Testing



CFPHS (blue) has better elongation and higher tensile strength than current PHS

Component 3pt Bend Testing

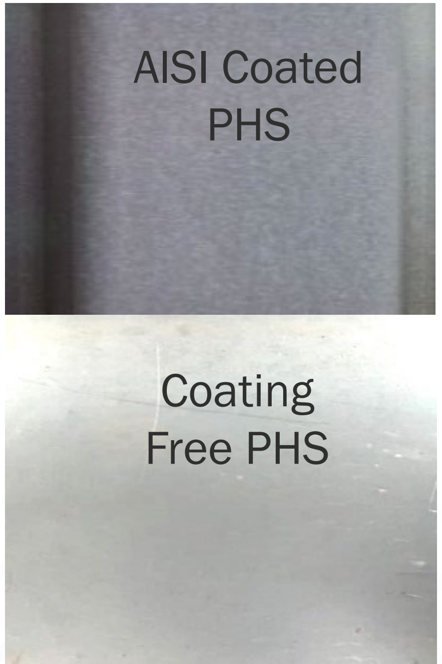


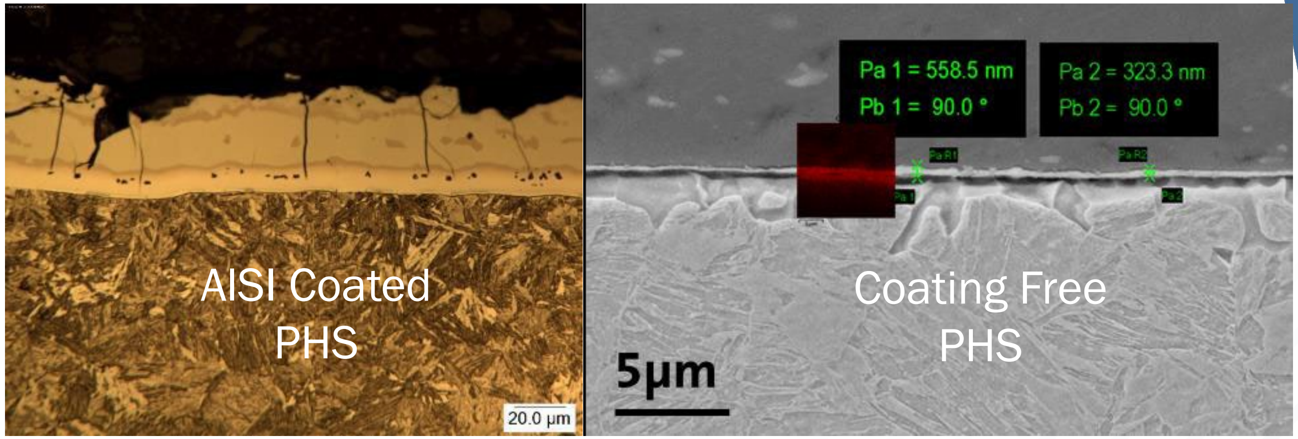
CFPHS (blue) has higher peak load and longer extension than 2 grades (1500MPa and 1800MPa) PHS

MANUFACTURABILITY AND SURFACE QUALITY

- CFPHS material developed to directly compete with current AlSi coated material in areas of manufacturability, surface quality, and strength.
- Chemistry is tailored with a higher Cr and Si content to promote the formation of a thin stable oxide layer to protect the material from excess oxidization and decarburization in the furnace.
- CFPHS can be heat treated in the same furnaces, formed and quenched in the same dies as the current PHS materials.

AlSi vs CFPHS surface finish. CFPHS has shinier and smoother finished appearance. Oxidation is kept to a minimum with proprietary chemistry.





AlSi vs CFPHS surface morphology: CFPHS has stable oxide layer which protects against oxidization and decarburization in the furnace without the application of a coating (cost savings).

PROJECT UPDATES AND FUTURE WORK

- CAE crash material card is nearly complete
- Door beams successfully produced at Gestamp Mason on P1LL door beams (more to share later in presentation)
  - Bend testing to be completed soon
- Application development: A-Pillar for drop-in (program not disclosed)
- Mini door ring 1:4 scale results
- Hot blow form tubular application development

LASER WELDING- LIKE TO LIKE

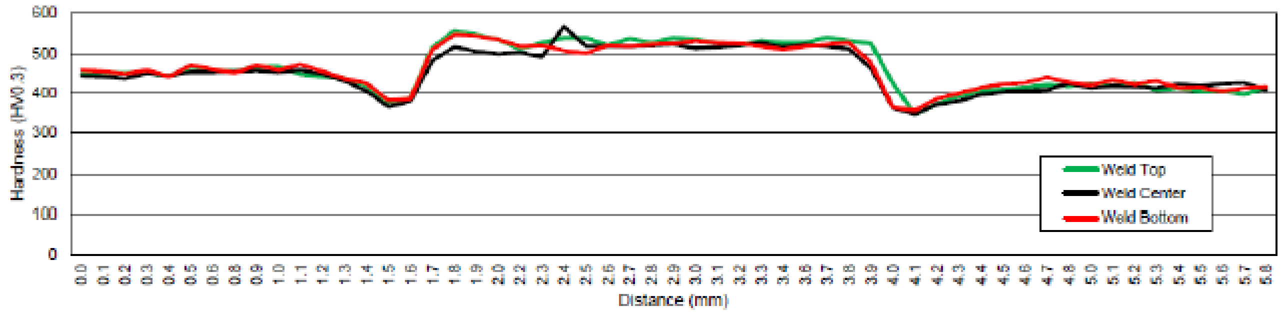
- Initial phase of this project included welding 1.9mm CFPHS to 1.9mm CFPHS.
- Laser welding was done without ablation or filler wire
  - Ablation and filler wire not necessary as there is no AlSi coating to pollute the weld
- Laser welding accomplished with minimal effects to the microstructure.
  - A refined martensitic microstructure in the weld zone was visible in the as welded sample
  - The final press hardened sample showed little difference between the base material and the weld zone

As Welded

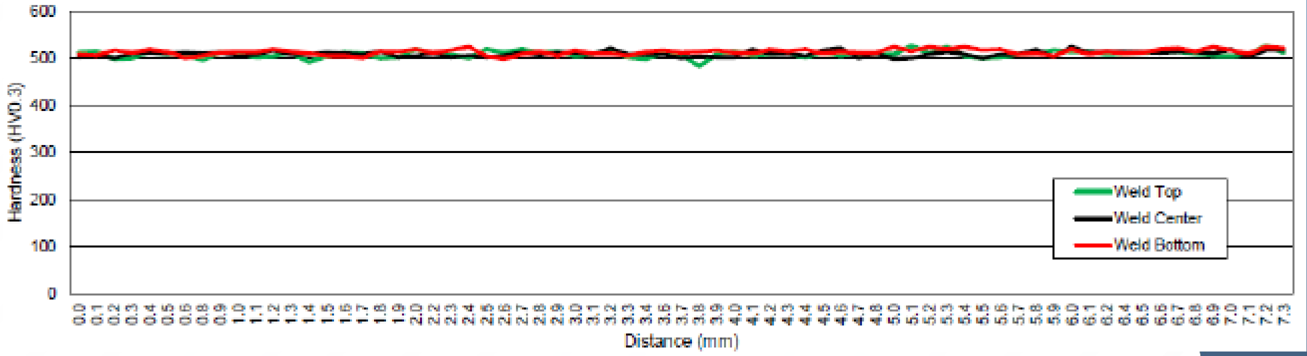
Press Hardened

WELD SEAM MICROHARDNESS

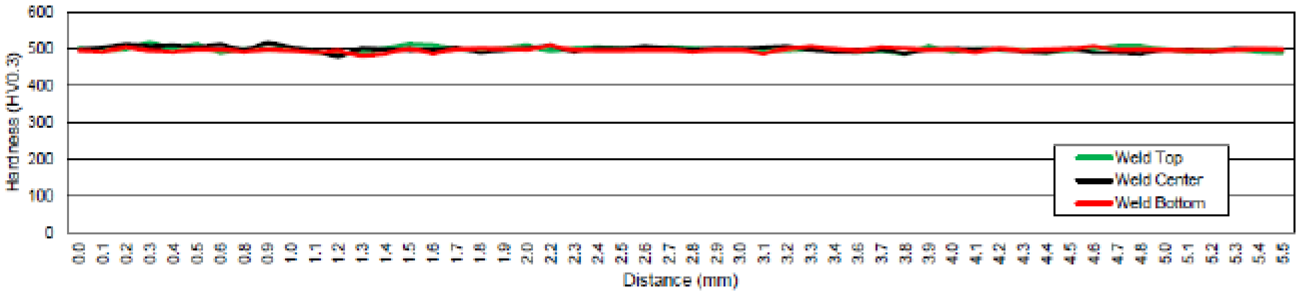
- Within the as-welded laser welded seam, there was a clear demarcation between the weld seam, HAZ and base material
- Weld seam to HAZ hardness differential not a concern as material is austenitized prior to forming.
- As press hardened, the weld seam is effectively “erased” leaving a homogenous hardness.
- After paint bake, the material is evenly tempered back, no differences seen between base material and the weld zone.



As Welded



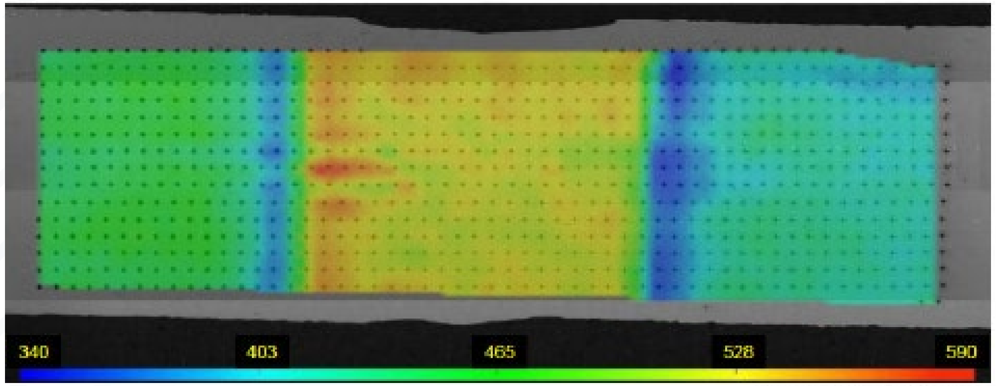
Press Hardened

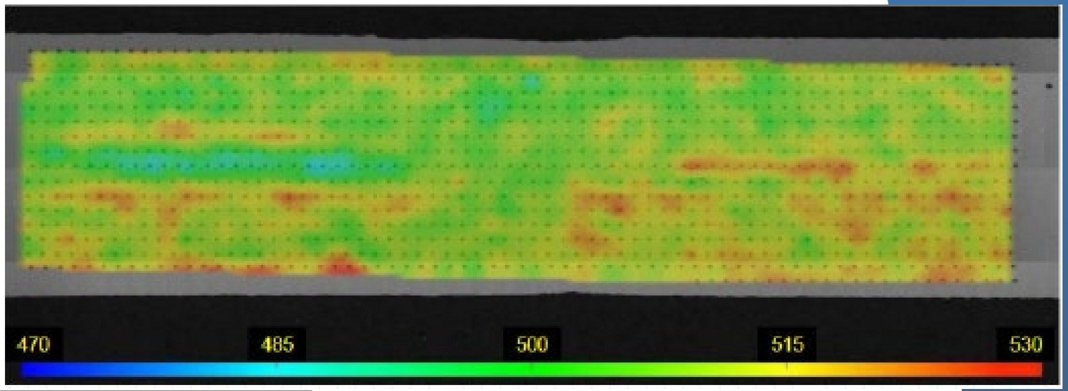


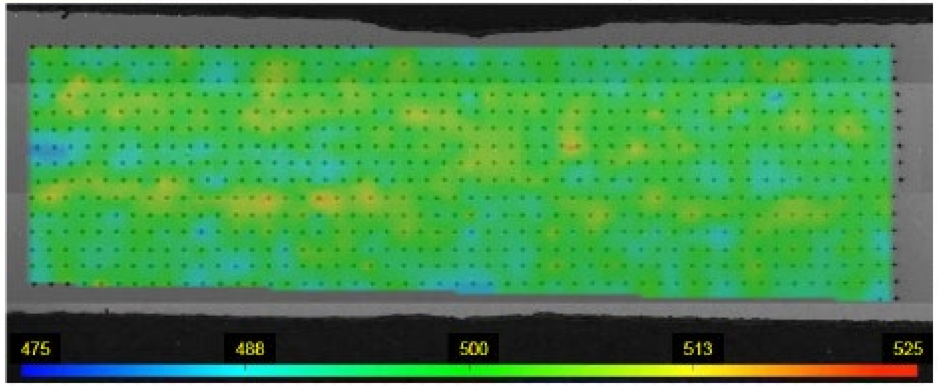
Press Hardened + Paint Bake

WELD SEAM MICROHARDNESS

Visual mapping of the weld seam shows homogeneous microstructure from top to bottom of the weld seam in both as welded, press hardened, and post paint bake samples.







As Welded (top left)
Press Hardened (top right)
Press Hardened + Paint Bake (bottom center)

TENSILE TESTING RESULTS OVERVIEW

- Tensile testing results in each stage:
  - ➢ As Welded
  - ➢ Press Hardened
  - ➢ Post Paint Bake
- Tensile testing with Digital Image Correlation (DIC)
  - ➢ Press Hardened
  - ➢ Post Paint Bake
- Comparison of results- standard tensile testing vs. DIC

TENSILE RESULTS- AS WELDED

- Results showed fracture in the parent metal to the side of the weld, as expected.
- Since the weld area is harder compared to the parent metal as welded, the material fractures in the parent metal.
- The extra strength of the as welded material can be attributed the resistance added by the strengthened weld.

Parent Metal

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	904	1399	8.9
2	901	1403	8.5
3	903	1399	8.7
Avg.	903	1400	8.7

As Welded

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1064	1413	9.5
2	1040	1382	9.0
3	983	1294	8.4
Avg.	1029	1363	9.0

TENSILE RESULTS-PRESS HARDENED

- Results showed the parent and welded samples are comparable in strength.
- The weld zone fractured in part due to geometrical factors of the weld being slightly thinner than the parent material

Parent, Press Hardened

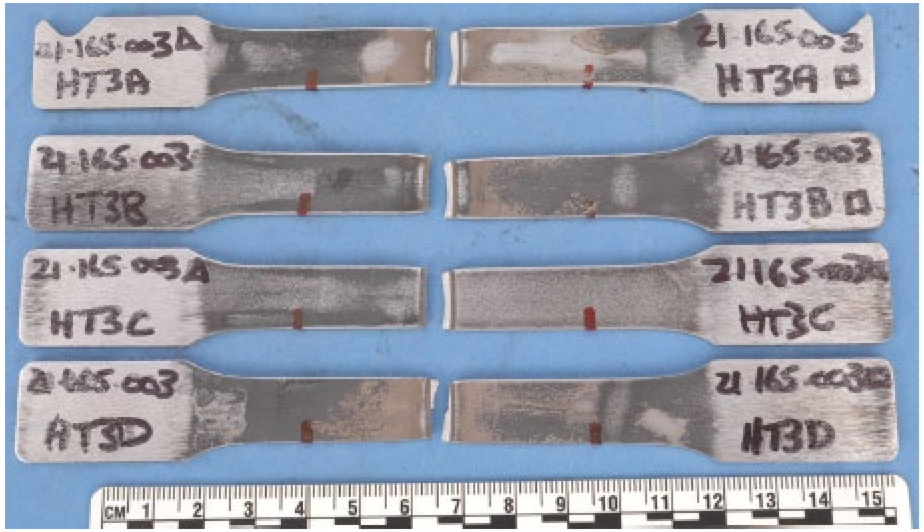
Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1020	1597	8.2
2	1049	1629	8.1
3	1083	1656	7.2
Avg.	**1051**	**1627**	**7.8**

Welded, Press Hardened

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1243	1626	5.5
2	1245	1631	4.9
3	1245	1636	5.3
4	1205	1599	6.5
Avg.	**1235**	**1623**	**5.6**

TENSILE RESULTS-PRESS HARDENED + PAINT BAKE

- Results showed the welded material tensile results are comparable to the parent material
- The weld seam fractured first due to the weld being slightly thinner than the parent metal



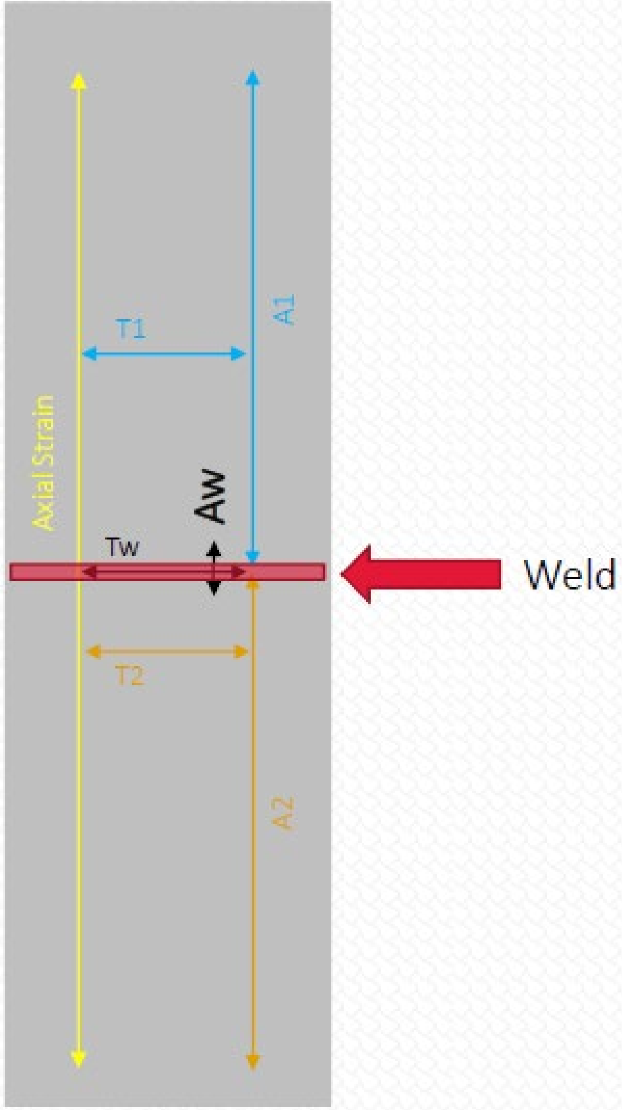
Parent, Press Hardened + Paint Bake

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1095	1539	8.5
2	1129	1577	8.2
3	1147	1581	8.7
Avg.	**1124**	**1566**	**8.5**

Welded, Press Hardened + Paint Bake

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1264	1579	4.8
2	1258	1573	4.6
3	1222	1545	4.4
4	1263	1575	4.5
Avg.	**1252**	**1568**	**4.6**

DIC TENSILE TESTING: METHOD



Schematic for the position of the seven (7) virtual extensometers in the CML Digital Image Correlation program for transverse welds:

1) **Axial Strain**: Axial Strain along the overall gauge length
2) A1: Axial Strain "above" the weld
3) A2: Axial Strain "below" the weld
4) AW: Axial Strain perpendicular to the narrow weld, 3mm
5) T1: Transverse Strain "above" the weld
6) T2: Transverse Strain "below" the weld
7) TW: Transverse Strain parallel to the narrow weld

Analogue 2 = Load (Newtons)
Analogue 3 = Crosshead (mm)

Tensile strain rates:

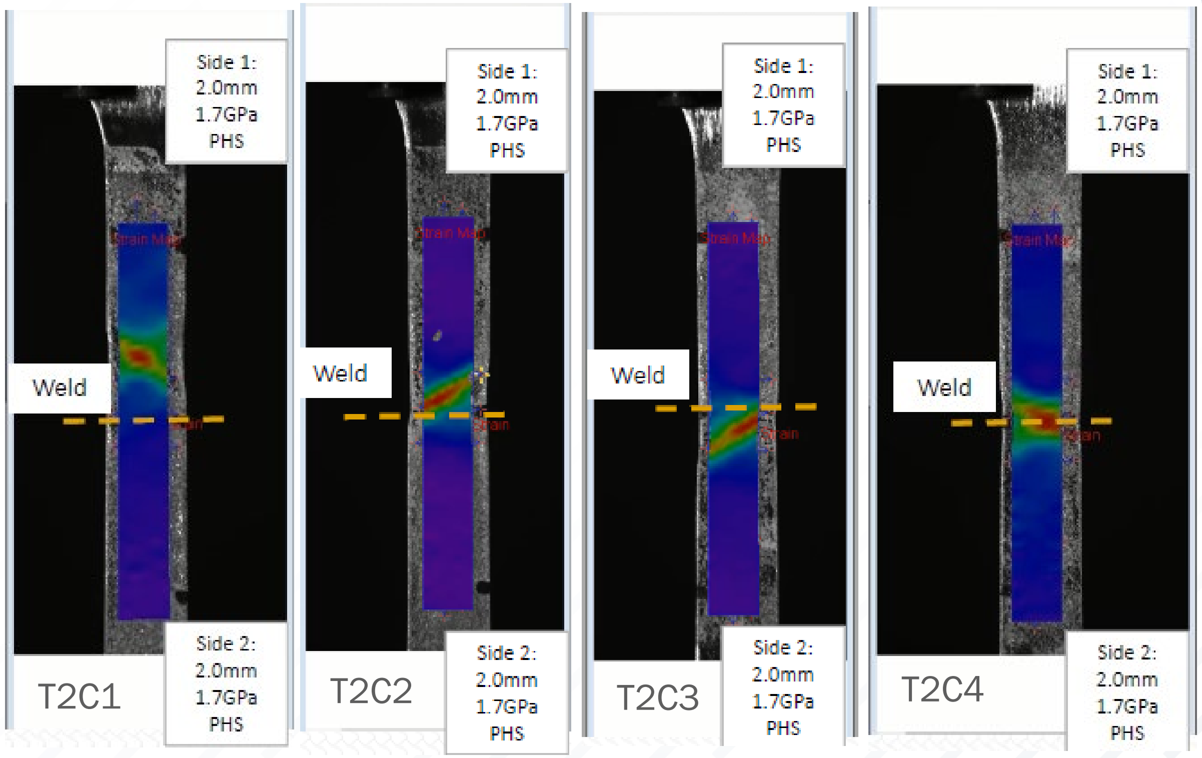
DIC crosshead speed 0.05 mm/sec

Standard TS 0.02%/sec from 0-2% strain, crosshead speed 0.05mm/sec after 2%

DIC TENSILE RESULTS- PRESS HARDENED

Results showed fractures in parent metal and the weld zone. Typical tensile failure was seen in 3 samples. Tensile results were comparable to parent material.

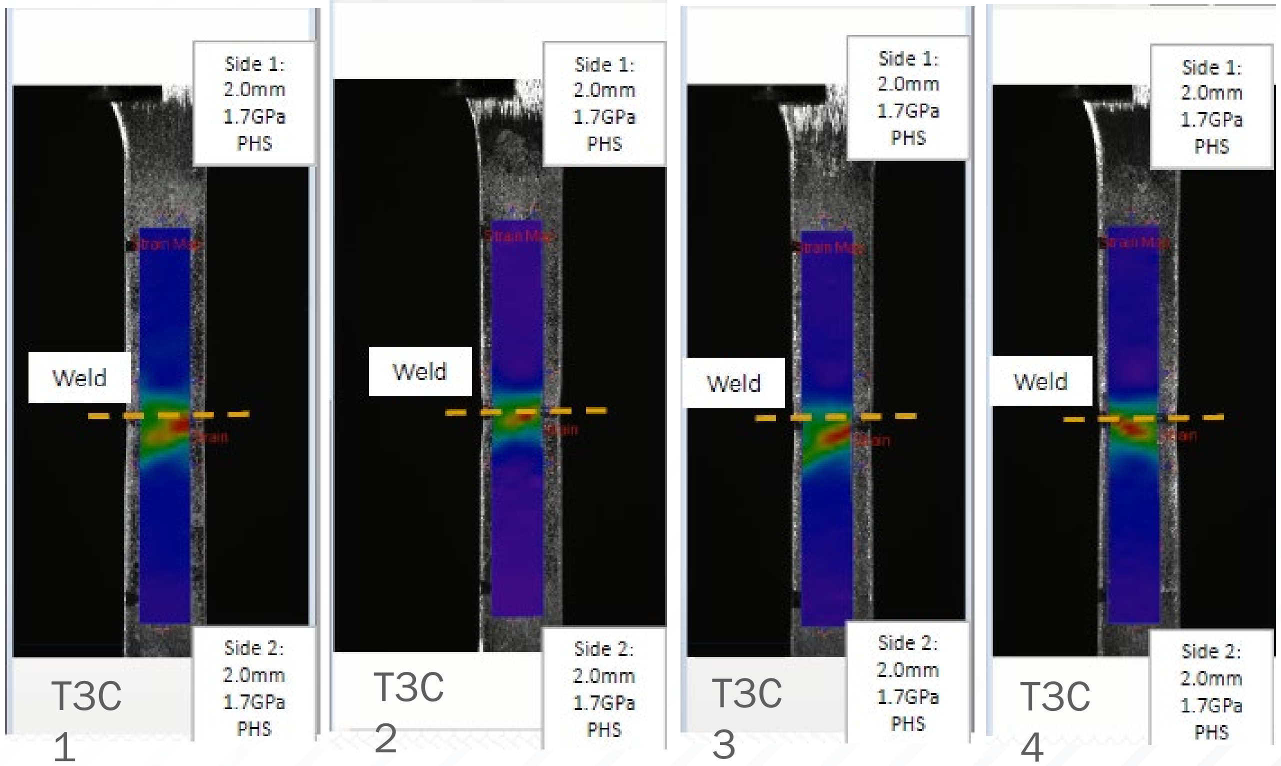
Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1056	1610	6.1
2	1099	1644	5.3
3	1116	1610	5.0
4	1075	1590	5.4
Avg.	1087	1614	5.5



DIC TENSILE RESULTS - PRESS HARDENED + PAINT BAKE

Results showed fractures in the weld zone for all 4 samples. Tensile results were comparable to parent material.

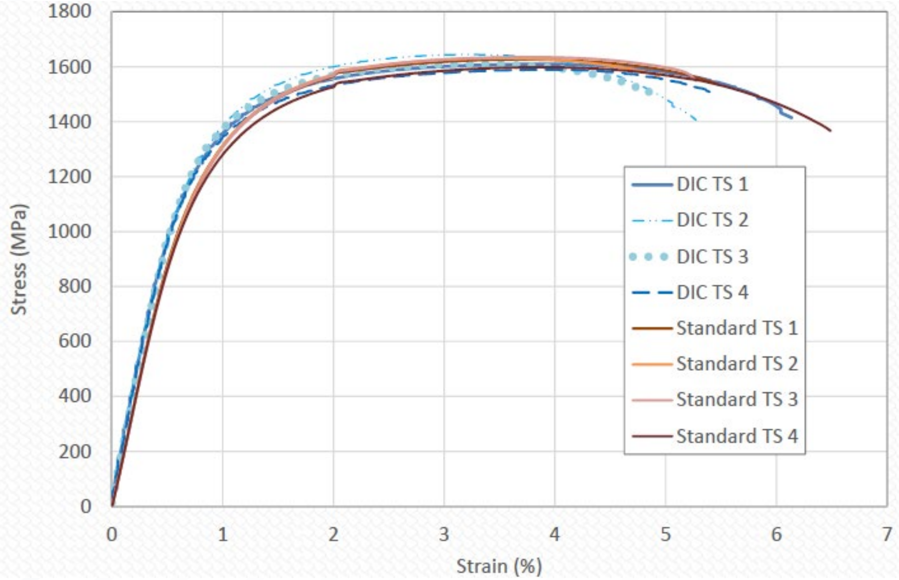
Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)
1	1134	1567	5.0
2	1180	1579	4.5
3	1171	1577	4.9
4	1139	1555	5.4
Avg.	1156	1570	4.9



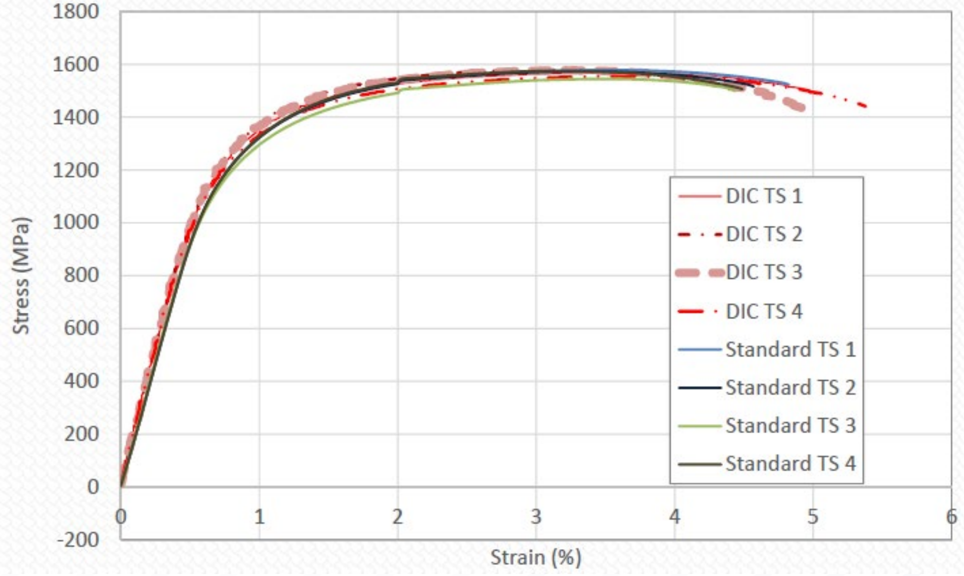
TENSILE RESULTS- STANDARD VS DIC

- Both sets of results showed comparable results to between the two tests
- Both tests resulted in curves typical of parent metal in both conditions

Press Hardened

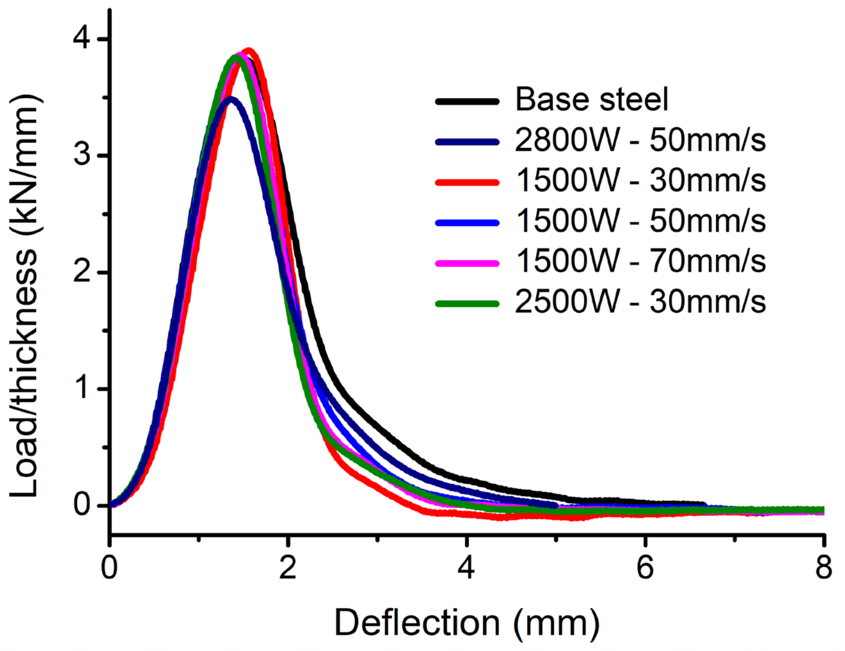


Press Hardened + Paint Bake



LASER WELDED IMPACT TESTING

- Samples were welded with various energy inputs ranging from 1500W to 2800W with Ar shielding gas
- Samples were ground at the weld seam prior to impact testing to eliminate variability from any surface imperfections
- Samples were tested for load deflection at various head speeds. Speeds varied from 30mm/s to 70mm/s
- 1500W samples were comparable to the 2500W samples. Both absorbed more impact energy than the 2800W samples.
- The 2800W sample weld seam contained pores, affecting the results



LASER WELDED IMPACT TESTING

- The results at various impact speeds are shown in the tables below
- Future studies will include head speeds of 50mm/s and 70mm/s for the 2500W samples

Weld Energy	30 mm/s	50 mm/s	70 mm/s
1500 W	61.7 ± 4.4 J cm^{-2}	65.8 ± 0.0 J cm^{-2}	63 ± 3.4 J cm^{-2}
2500 W	63.7 ± 5.2 J cm^{-2}	On the way	On the way
Base steel	76.1 ± 6.2 J cm^{-2}		

Results showing energy absorbed by various samples and head speeds. Total energy is listed above and maximum load energy is listed below.

Weld Energy	30 mm/s	50 mm/s	70 mm/s
1500 W	31.6 ± 2.5 J cm^{-2}	30.4 ± 0.0 J cm^{-2}	30.5 ± 0.3 J cm^{-2}
2500 W	29.5 ± 2.0 J cm^{-2}	On the way	On the way
Base steel	32.8 ± 0.8 J cm^{-2}		

SUMMARY

- Laser welded raw material showed a fine-grained martensitic microstructure in the weld seam, with a HAZ surrounding the weld area (microhardness map)
- Press hardened weld seams showed uniform martensitic microstructure with equalized hardness across the weld zone (microhardness map)
- Tensile specimens of the as-welded showed parent metal fracture
- Heat treated samples showed fractures in the weld seam due to small geometric thickness variation within the weld seam
- DIC was used to quantify and localize the stresses within the weld sample. DIC samples showed variation in the location of fracture
    - Fracture occurred in the parent metal in one instance
    - Primarily fracture occurred in the weld seam.
- DIC results correlated well with the standard testing results. All correlated back to the parent material results. Strength of material not adversely impacted by the welding process post heat treatment.
- 1500W laser power was sufficient to achieve optimal impact testing energy absorption
- Conclusions: laser welding of CFPHS to CFPHS shows good promise for future applications in terms of weld seam uniformity and integrity of weld seam in crash situations

IN THANKS TO OUR PARTNERS!

Thank you to the TWB Monroe, MI team for all the hard work. Without their contributions, the information shared today would not have been possible.

Thanks for your attention!