GREAT DESIGNS IN STEEL

TWENTY YEARS

FORMABILITY EVALUATIONS OF AHSS LASER-WELDED BLANK

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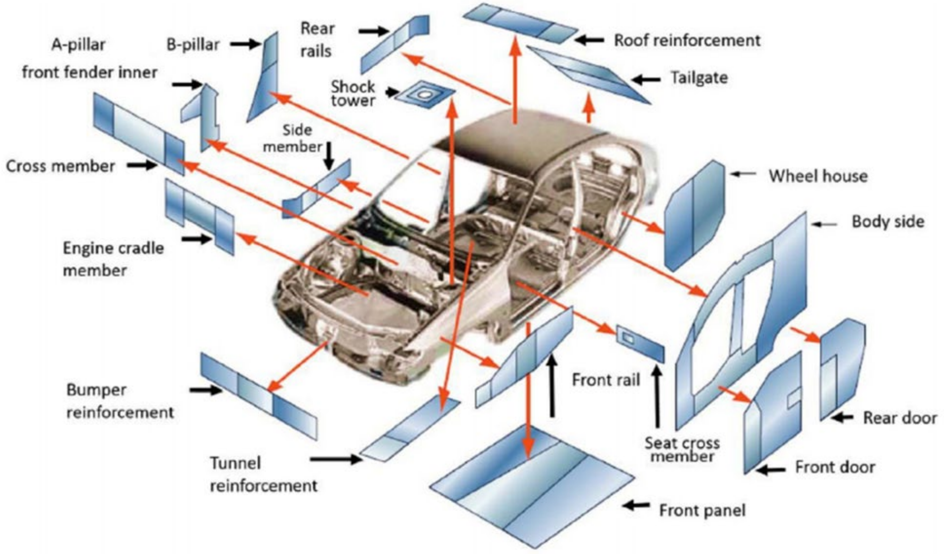
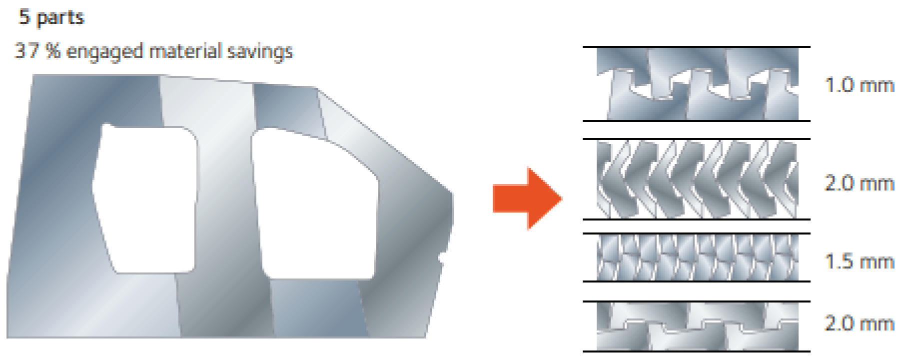
On Behalf of Auto/Steel Partnership

BACKGROUND

- Laser-welded blank (LWB) are widely applied to automotive closures, body-in-white and chassis structures
- Major benefits of LWBs:
  - Light-weighting
  - Improved material utilization
  - Improved crashworthiness
  - Reduced overall production costs through part consolidation



Applications suited for welded tailored blanks (ArcelorMittal)

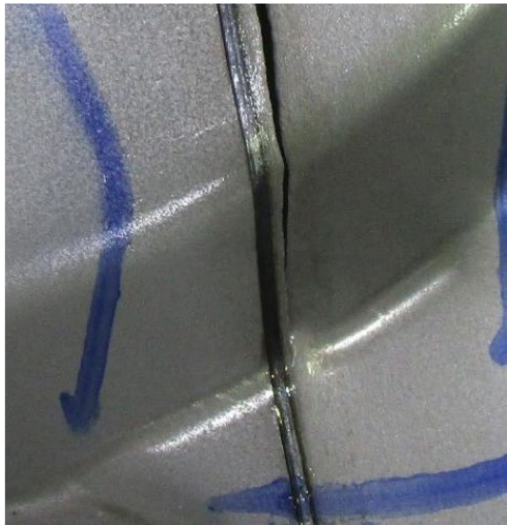


Material savings with LWB in a body side inner (ArcelorMittal)

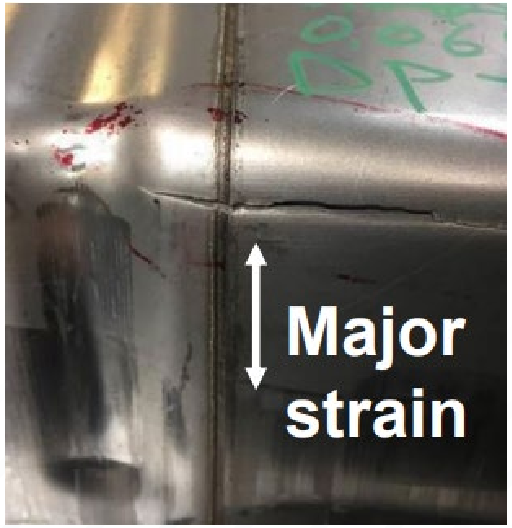
Crushing of butt-welded beams (ArceloMittal)

TECHNICAL GAPS

- The formability of LWBs is greatly influenced by:
  - Base metal (BM) properties
  - Thickness and strength ratios of the welded steels
  - Weld - orientation, location, and heat affected zone (HAZ)
- AHSS welds exhibit less ductile weld seams that are difficult to predict with standard forming simulations
- Designers should understand the reduced formability and unique behavior of LWBs during forming



Base metal fracture



Weld fracture

OBJECTIVES

- Determine the forming limit and fracture characteristics of LWBs under uniaxial tension, plane-strain tension, and biaxial tension
- Understand the relationship between microstructure/micro-hardness profiles and the formability of various LWBs
- Develop material models for the laser weld to be used as inputs to forming simulations of LWBs to substantially enhance simulation accuracy

SELECTED LASER WELDED BLANK MATERIALS

- Nine different LWB combinations were fabricated for the project.

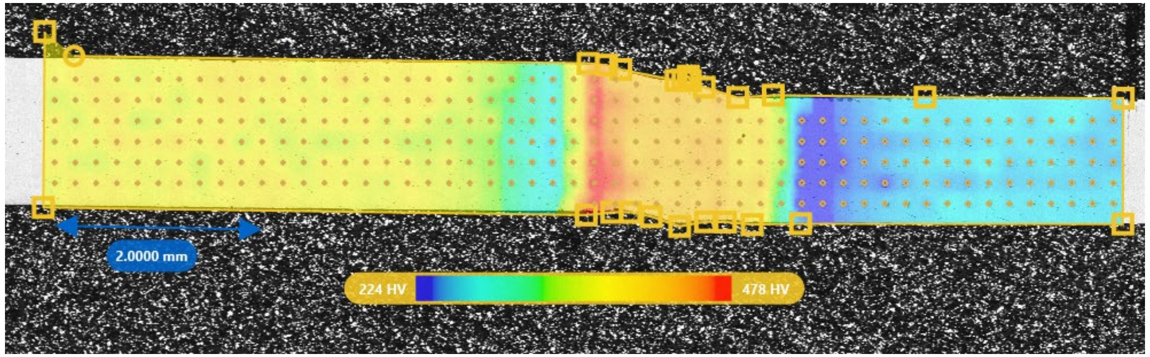
Weld Couple	Sample ID	Base Metal 1	Base Metal 2
1	SM-ST-1	HSLA 340 (1.2 mm)	HSLA 340 (1.2 mm)
2	SM-ST-2	CR3 (1.2 mm)	CR3 (1.2 mm)
3	SM-ST-3	DP980 (1.6 mm)	DP980 (1.6 mm)
4	SM-ST-4	DP1180 (1.4 mm)	DP1180 (1.4 mm)
5	SM-ST-5	DP780 (1.2 mm)	DP780 (1.2 mm)
6	SM-DT-1	HSLA 340 (1.2 mm)	HSLA 340 (2.6 mm)
7	SM-DT-2	DP980 (1.6 mm)	DP980 (1.3 mm)
8	DM-ST-1	CR3 (1.2 mm)	HSLA 340 (1.2 mm)
9	DM-DT-4	DP1180 (1.4 mm)	DP780 (1.2 mm)

- SM-ST: Same Material Same Thickness
- SM-DT: Same Material Different Thickness
- DM-ST: Different Material Same Thickness
- DM-DT: Different Material Different Thickness

HARDNESS MAP DATA

DM-DT-4: DP1180 (1.4 mm) + DP780 (1.2 mm)

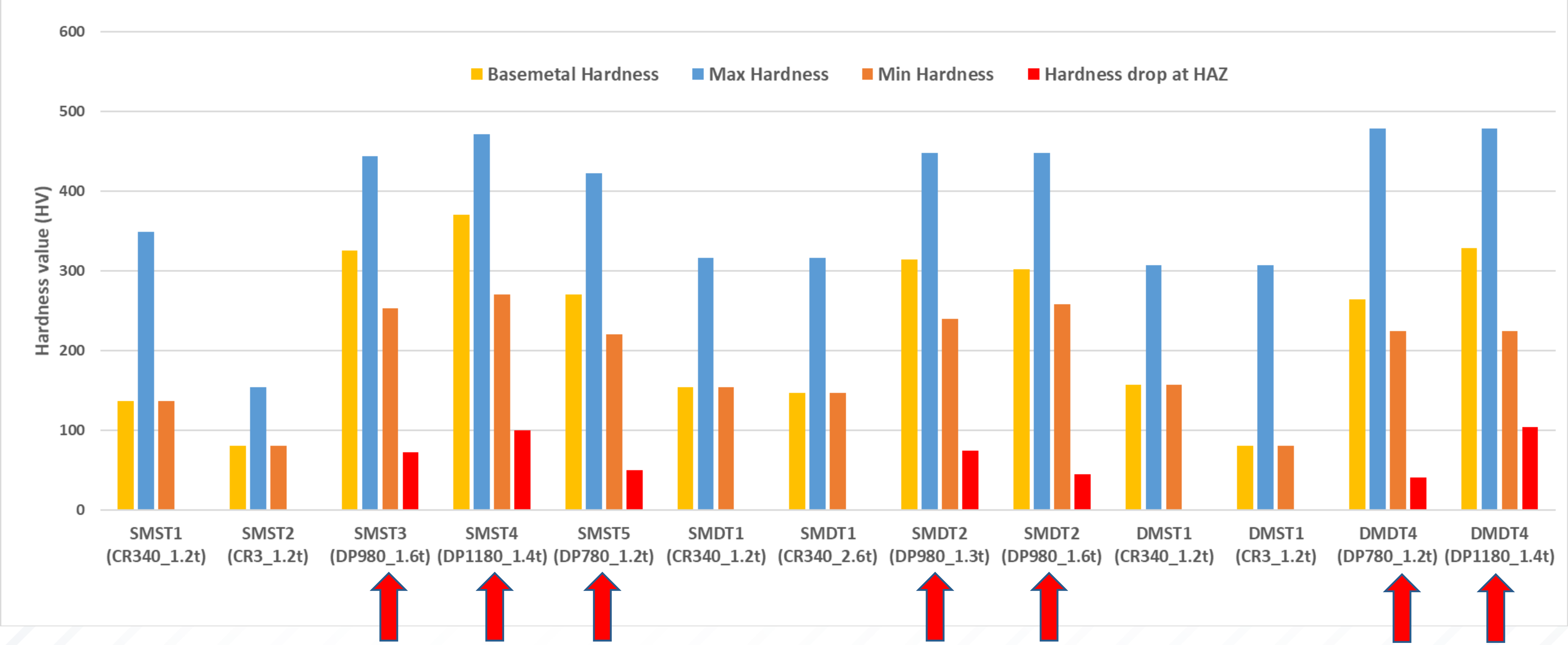
- Max. Hardness: 479 HV
- Min. Hardness: 224 HV
- LWBs with DP steels show hardness drops between HAZ and base metal:
  - 104 HV for DP1180
  - 30 HV for DP780



*Applied load for micro-hardness testing: 300 grams

VARIATION OF HARDNESS PROFILES

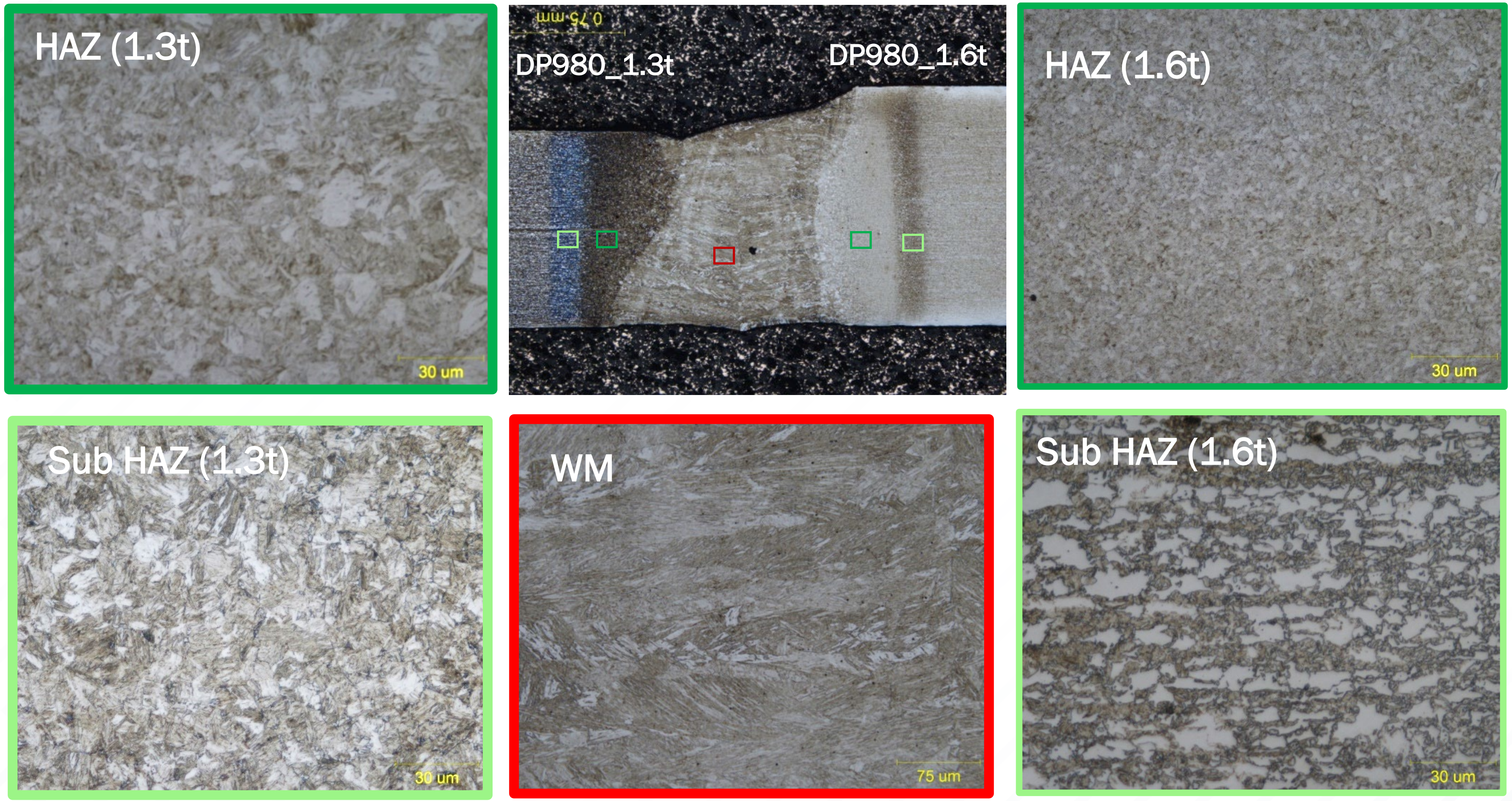
- All three DP steels show distinguishable hardness drops in HAZ (i.e., HV_{weld} > $HV_{basemetal}$ > HV_{HAZ}).



Note: Results are based on steel samples from the A/SP and should not be applied to all steel suppliers.

MICROSTRUCTURE EXAMPLE

SM-DT2: DP980 (1.6 mm) + DP980 (1.3 mm)

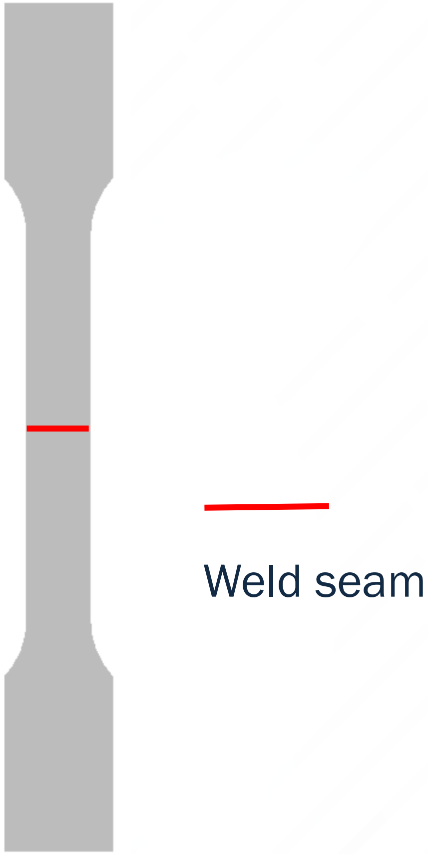


- Microstructure varies in weld metal (WM), HAZ, and BM.
- Different gauges and grades influence the microstructure in HAZ and Subcritical HAZ.

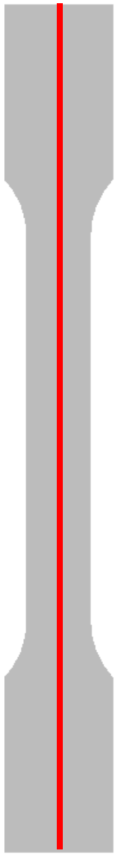
UNIAXIAL TENSILE TESTS

- Four different tensile tests were preformed to characterize the formability of the LWB under uniaxial tension.

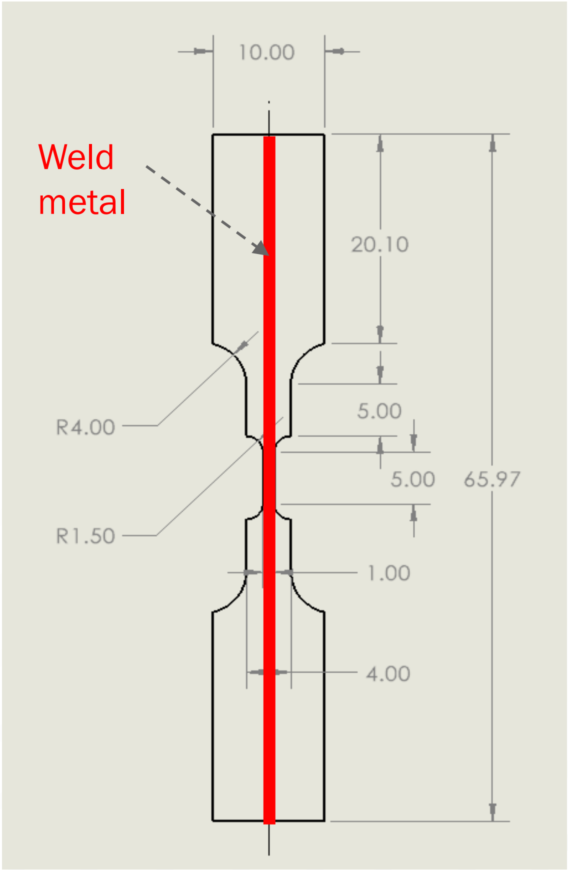
Base metal tensile test



LWB tensile test with a horizonal weld



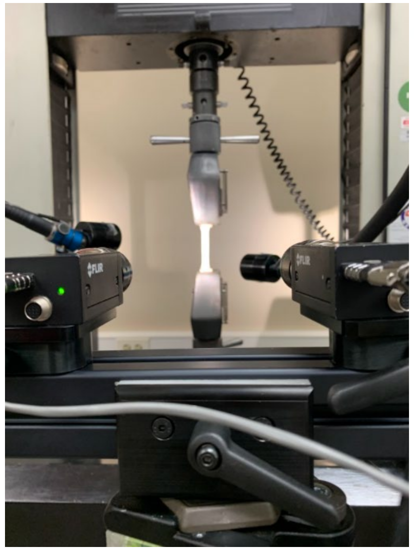
LWB tensile test with a vertical weld

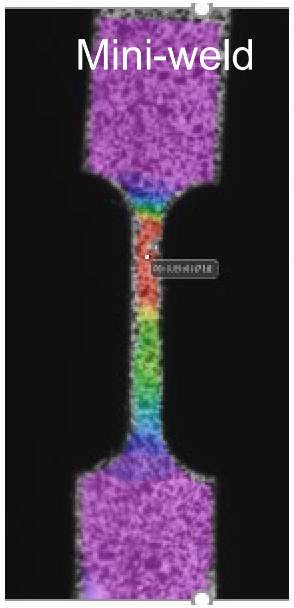


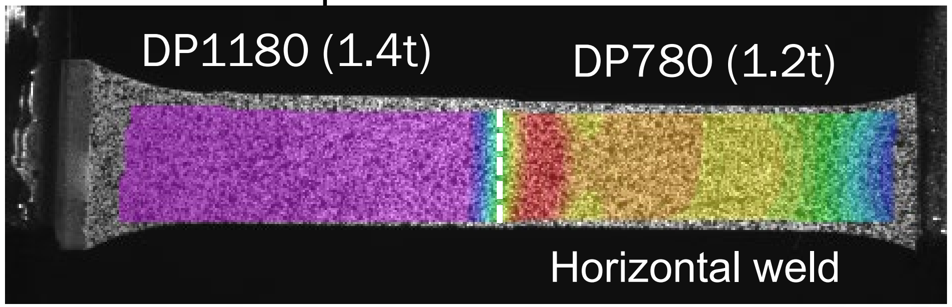
Mini-tensile test for weld

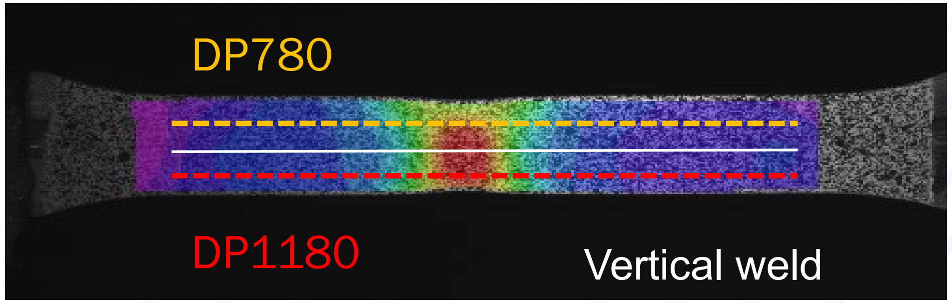
EXPERIMENTAL SETUP

- Instron 5500R 10-kip static tensile frame was used for the uniaxial tensile test
- Crosshead speed: 0.012 inch/min (Quasi-static)
- Analog data was synchronized with the digital image correlation (DIC) system
- Data acquisition software: Vic-Snap-6
- Postprocessing software: Vic-3D 8
- No shim was used in DM-DT-4 (1.4 - 1.2-mm thickness) sample due to sufficient grip contact
- 10 Hz image capture rate (10 frames/sec)
- DIC time step has minimal interruption by using high-speed SSD

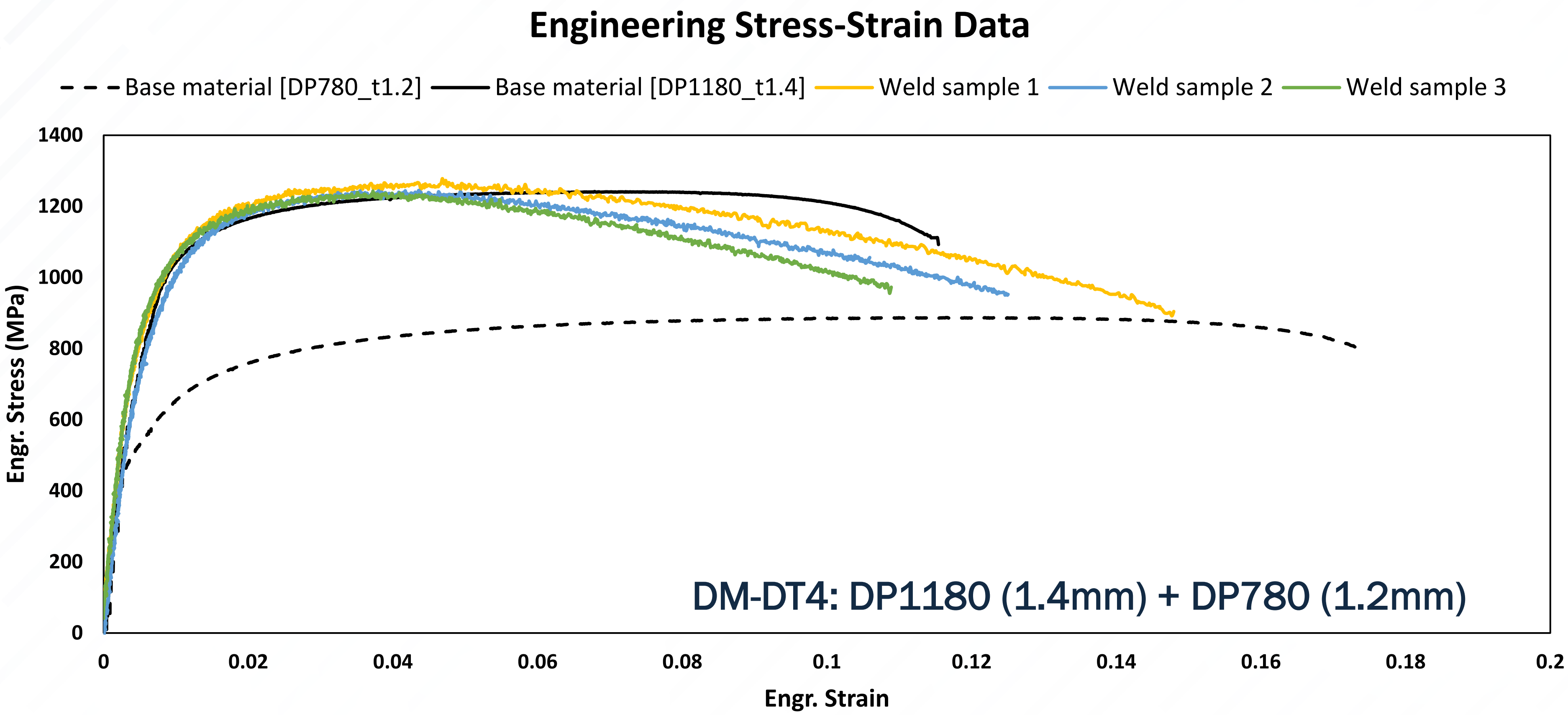

DIC setup







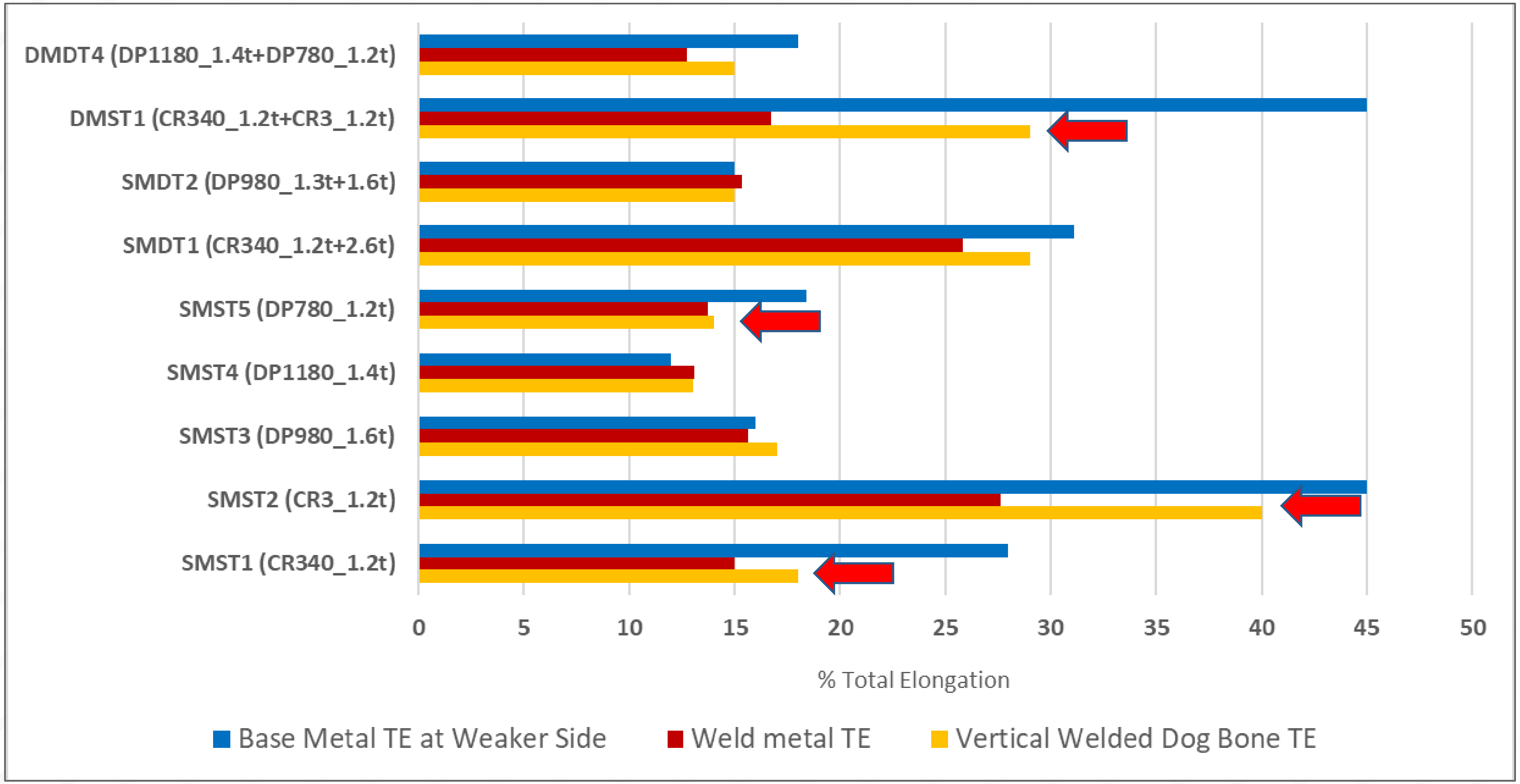
WELD MATERIAL VS. BASE MATERIALS



- The standard tensile test was used for both base materials while the mini-weld tensile used for the weld metal.
- The weld metal shows similar yield and tensile strengths with the DP1180 rather than DP780.
- The weld metal shows 50% reduction of the uniform elongation compared to DP1180.

COMPARISON OF TOTAL ELONGATION

$\text{Mean}\ (TE_{base} + TE_{mini\text{-}weld}) \approx TE_{vertical\ weld\ tensile}$



BM Tensile

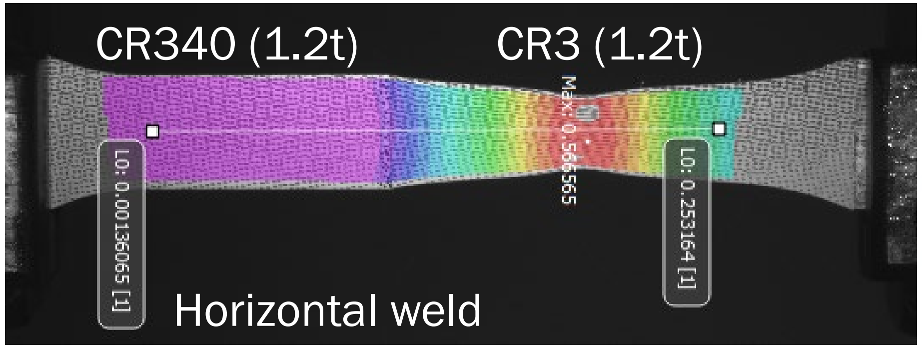
Mini-weld tensile

Vertical Weld Tensile

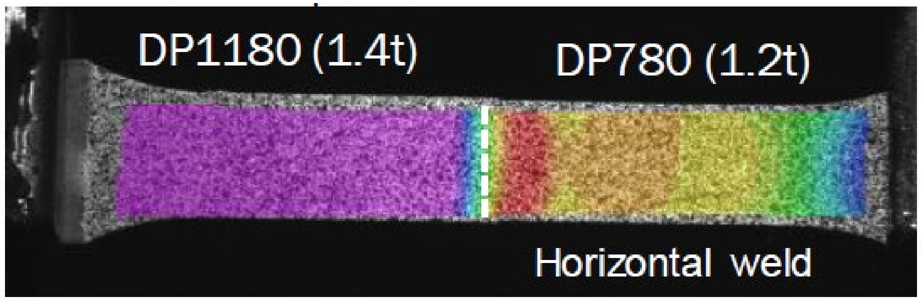
HORIZONTAL TENSILE TEST

- The majority of tensiles with HAZ hardness drop fractured at the weld or HAZ.

Sample ID	Hardness Drop (HV)	LWB Fracture Location
SM-ST-1: CR340 (1.2MM)	0	Base metal
SM-ST-2: CR3 (1.2MM)	0	Base metal
SM-DT-1: CR340 (1.2MM) + CR340 (2.6MM)	0	Base metal
DM-ST-1: CR340 (1.2MM) + CR3 (1.2MM)	0	Base metal



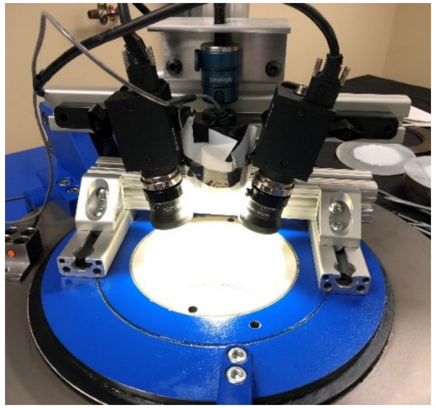
Sample ID	Hardness Drop (HV)	LWB Fracture Location
SM-ST-3: DP980 (1.6MM)	72	Base metal
SM-ST-4: DP1180 (1.4MM)	100	Weld or HAZ
SM-ST-5: DP780 (1.2MM)	50	Weld or HAZ
SM-DT-2: DP980 (1.2MM) + DP980 (1.6MM)	74	Weld or HAZ
DM-DT-4: DP1180 (1.4MM) + DP780 (1.2MM)	104	Weld or HAZ



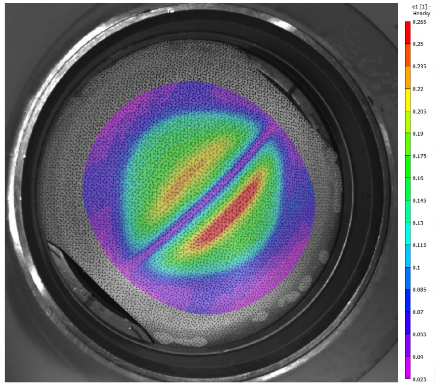
EXPERIMENTAL SETUP FOR PLANE-STRAIN AND BIAXIAL STRETCH TESTS

- Most experiments were performed using a standard dome punch in the Erichsen Universal Sheet Metal Testing Machine with DIC.

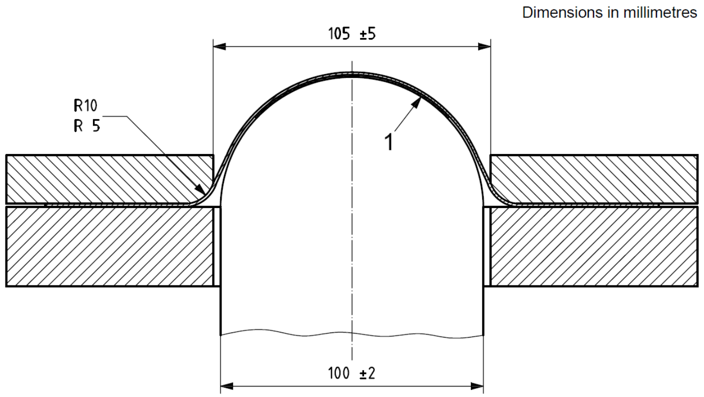
Erichsen Universal Sheet Metal Testing Machine



DIC setup



DIC measured strain



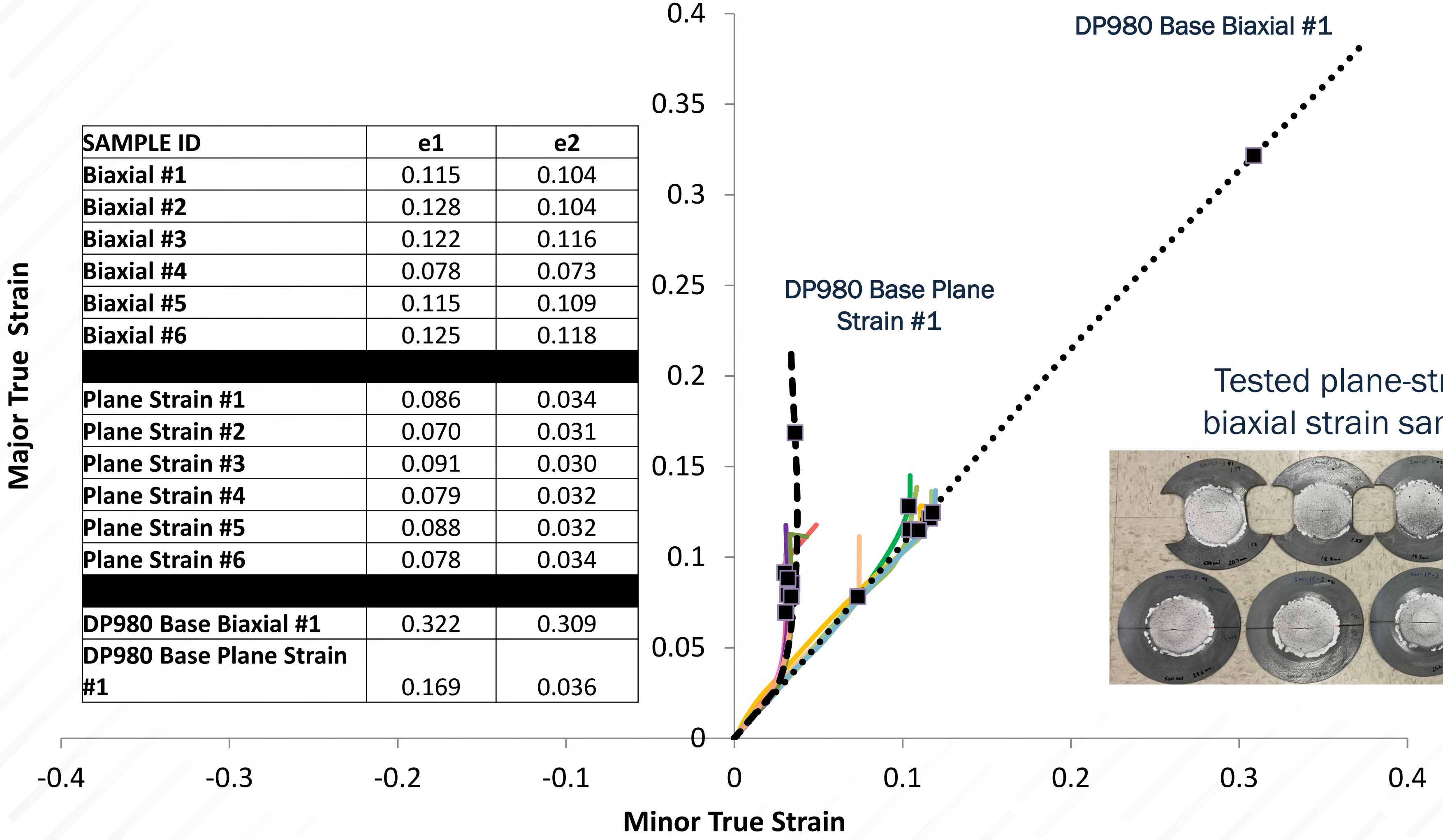
The 4-in. (101.6-mm) diameter dome punch (Ref. ISO 12004)

Forming Parameters	
Punch Diameter	101.6 mm
Punch Speed	~1.0 mm/s
Blank holder Force	500 kN
Lubricant	Tallow with Teflon

STRAIN PATHS OF BIAXIAL AND PLANE-STRAIN SAMPLES

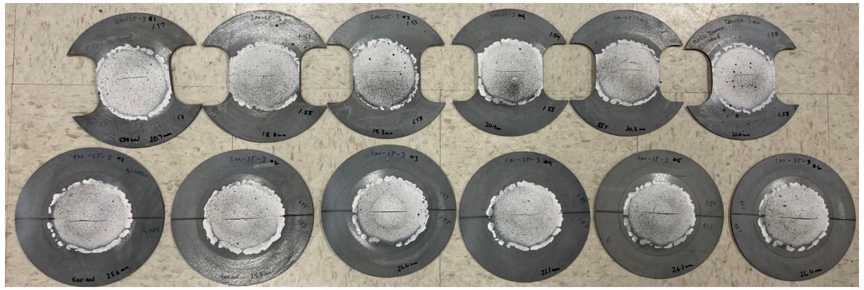
SM-ST-3: DP980 (Lot 24) – DP980 (Lot 24)

- Same gauge and strength LWBs (SM-ST) kept the biaxial and plane-strain strain paths.



SAMPLE ID	e1	e2
Biaxial #1	0.115	0.104
Biaxial #2	0.128	0.104
Biaxial #3	0.122	0.116
Biaxial #4	0.078	0.073
Biaxial #5	0.115	0.109
Biaxial #6	0.125	0.118
Plane Strain #1	0.086	0.034
Plane Strain #2	0.070	0.031
Plane Strain #3	0.091	0.030
Plane Strain #4	0.079	0.032
Plane Strain #5	0.088	0.032
Plane Strain #6	0.078	0.034
DP980 Base Biaxial #1	0.322	0.309
DP980 Base Plane Strain #1	0.169	0.036

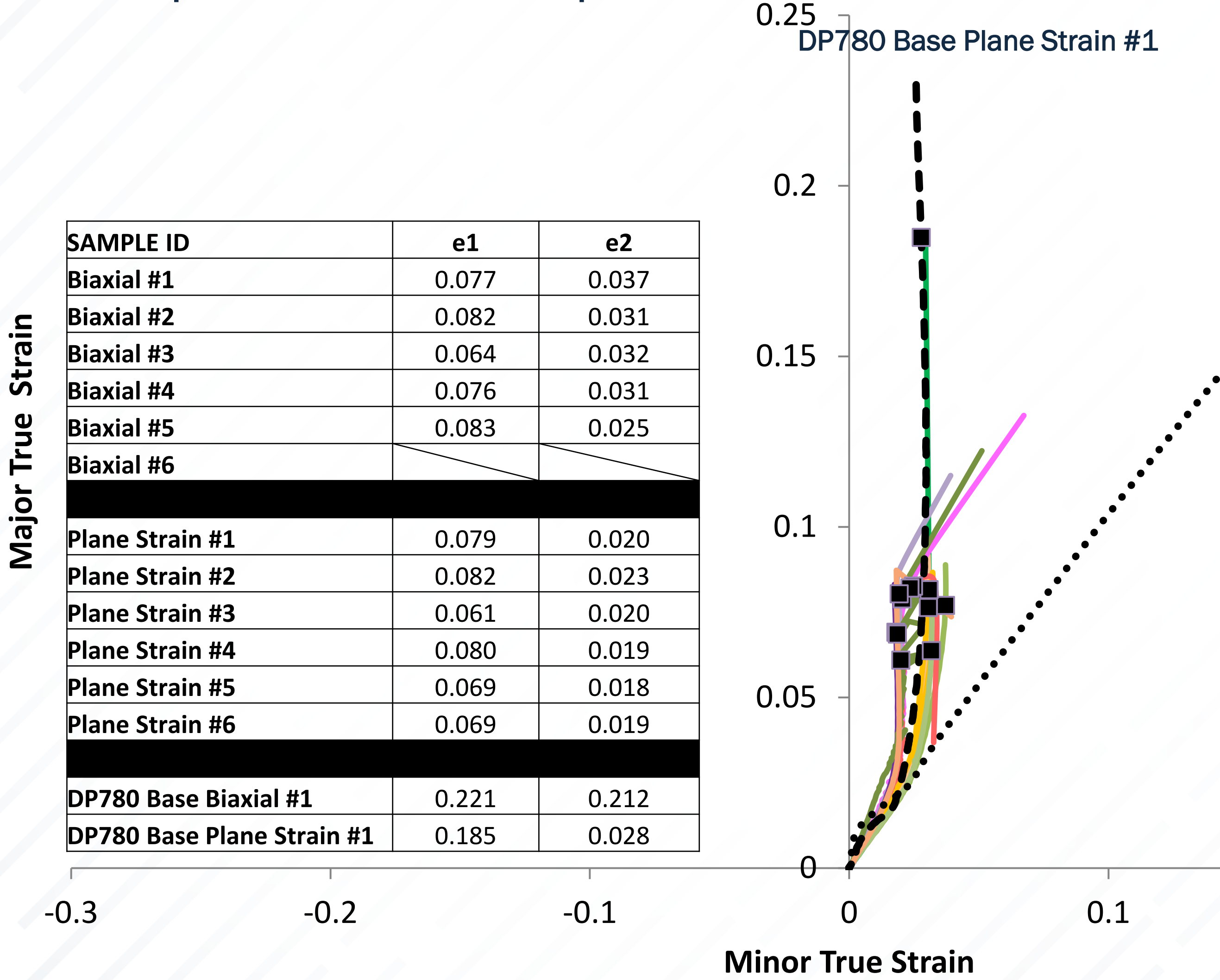
Tested plane-strain (first row) and biaxial strain samples (second row)



STRAIN PATHS OF BIAXIAL AND PLANE-STRAIN SAMPLES

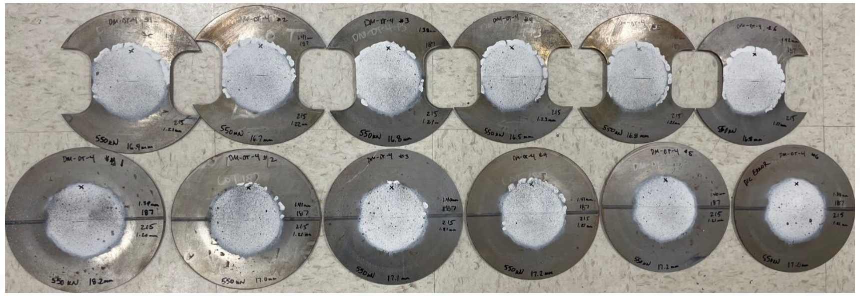
DM-DT-4 (DP1180 + DP780)

- Different gauge and strength LWBs (SM-DT and DM-ST) showed the biaxial samples' strain path shifted to the plane-strain condition.



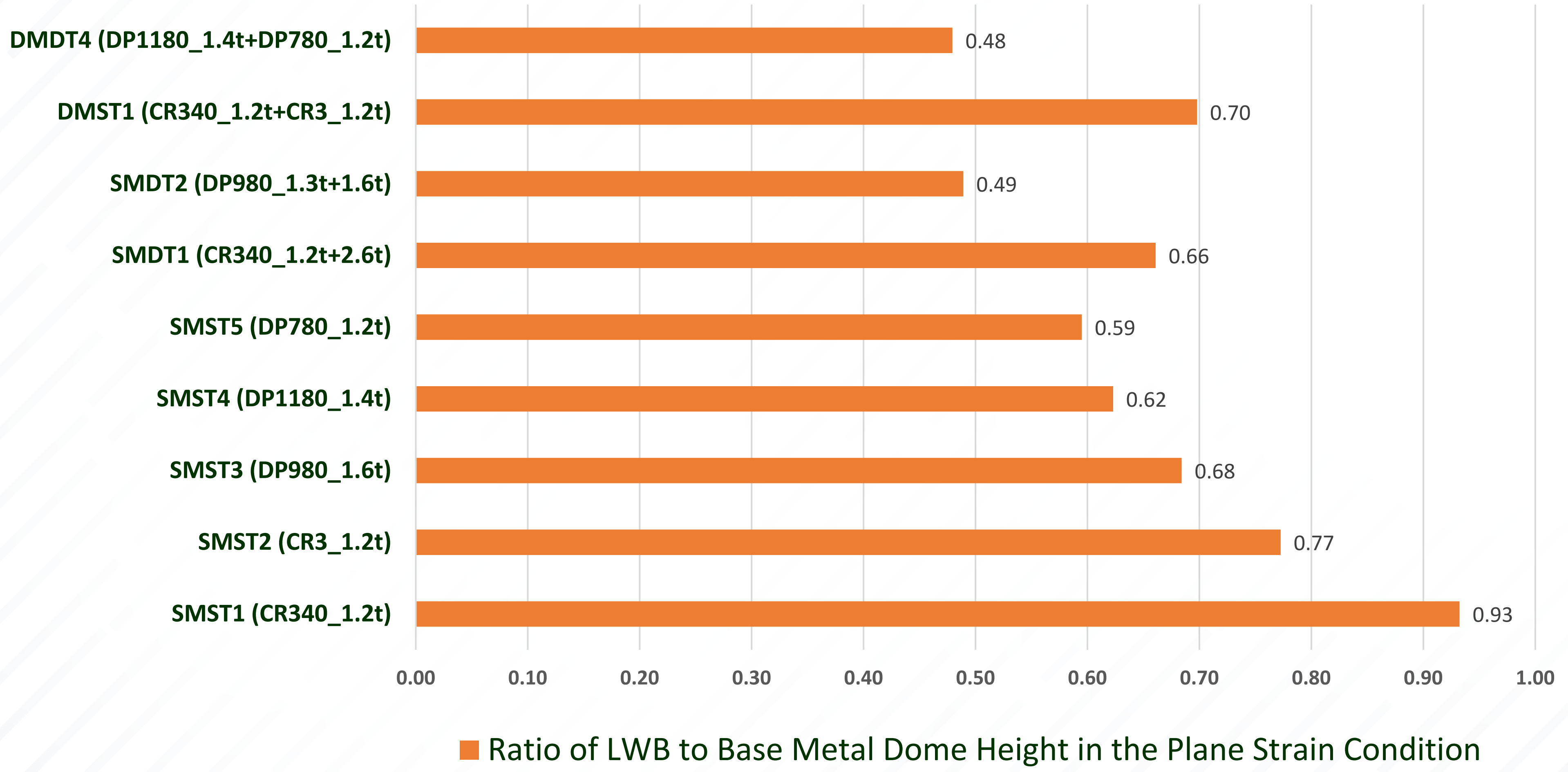
SAMPLE ID	e1	e2
Biaxial #1	0.077	0.037
Biaxial #2	0.082	0.031
Biaxial #3	0.064	0.032
Biaxial #4	0.076	0.031
Biaxial #5	0.083	0.025
Biaxial #6		
Plane Strain #1	0.079	0.020
Plane Strain #2	0.082	0.023
Plane Strain #3	0.061	0.020
Plane Strain #4	0.080	0.019
Plane Strain #5	0.069	0.018
Plane Strain #6	0.069	0.019
DP780 Base Biaxial #1	0.221	0.212
DP780 Base Plane Strain #1	0.185	0.028

Tested plane-strain (first row) and biaxial strain samples (second row)



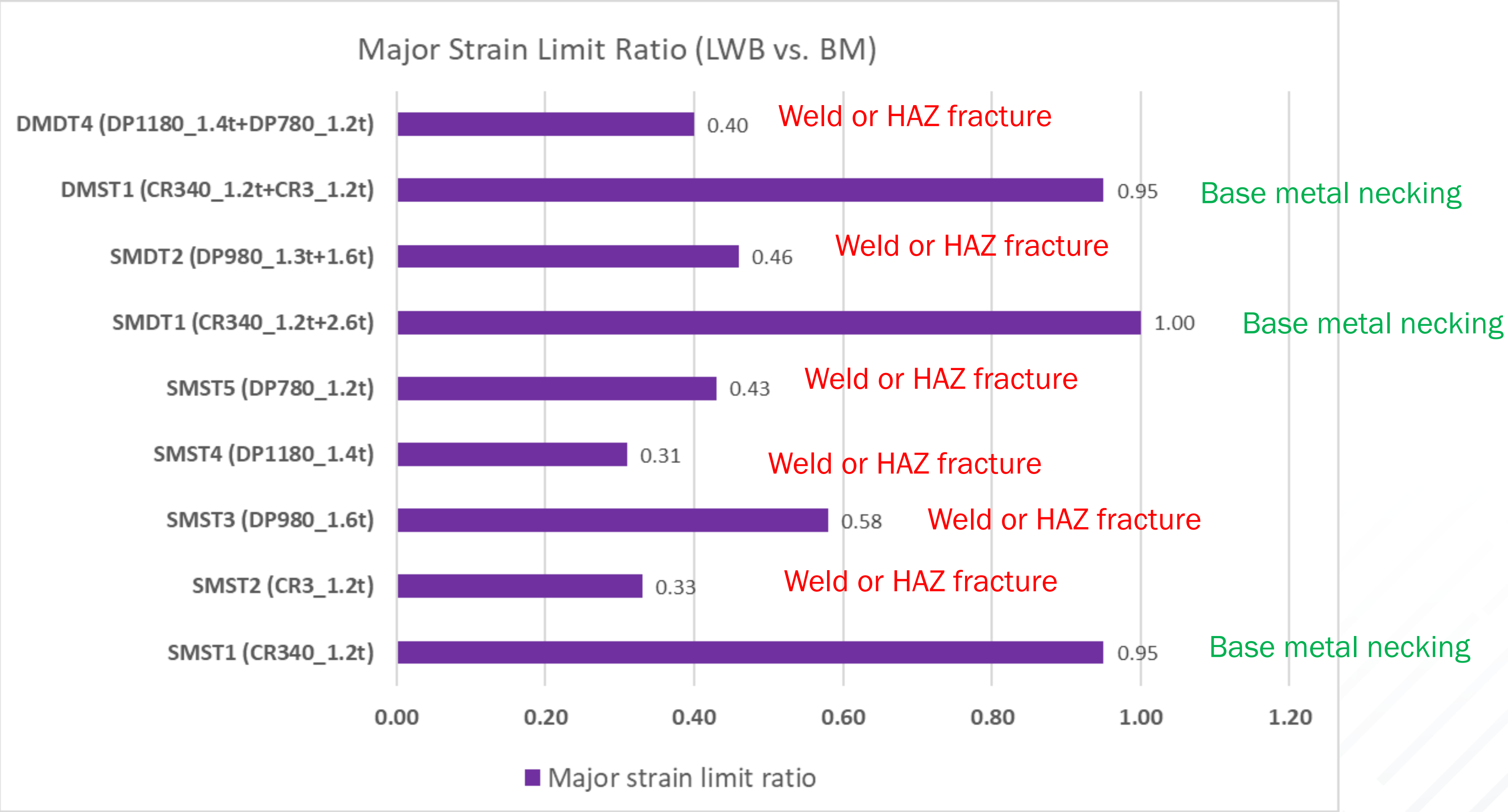
DOME HEIGHT RATIO FOR THE PLANE-STRAIN CONDITION

- LWB without a HAZ hardness drop averaged a 7% to 34% dome height reduction.
- LWB with a HAZ hardness drop averaged a 32% to 52% dome height reduction.



MAJOR STRAIN LIMIT RATIO (LWB VS. BM)

- Major strain limit ratio ($a_{LB} = \varepsilon_{1,\ LWB} / \varepsilon_{1,\ BM}$) of LWB and BM is well correlated to base metal necking and weld or HAZ fracture.
- When $a_{LB} < 0.95$, weld fracture; when $a_{LB} \geq 0.95$ base metal necking.



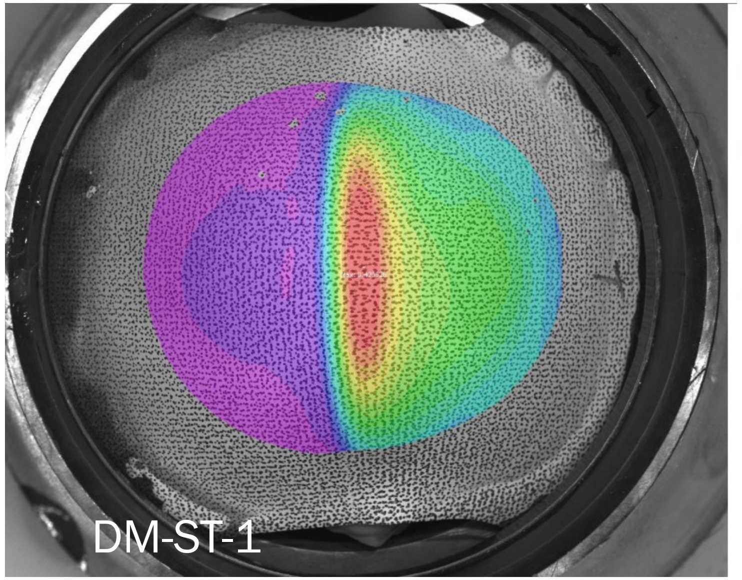
PLAIN-STRAIN FRACTURE LOCATION

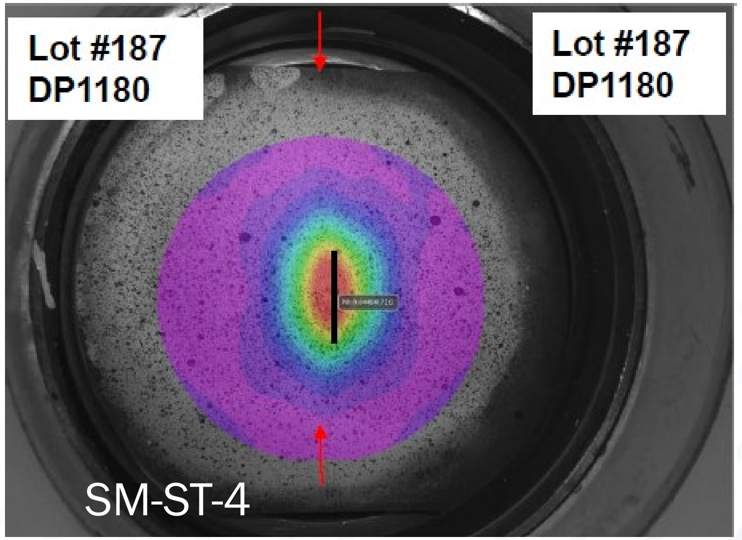
- Hardness drop in HAZ strongly influences fracture location.

Sample ID	Hardness Drop (HV)	LWB Fracture Location
SM-ST-1: CR340 (1.2MM)	0	Base metal
SM-ST-2: CR3 (1.2MM)	0	Weld or HAZ
SM-DT-1: CR340 (1.2MM) + CR340 (2.6MM)	0	Base metal
DM-ST-1: CR340 (1.2MM) + CR3 (1.2MM)	0	Base metal

Sample ID	Hardness Drop (HV)	LWB Fracture Location
SM-ST-3: DP980 (1.6MM)	72	Weld or HAZ
SM-ST-4: DP1180 (1.4MM)	100	Weld or HAZ
SM-ST-5: DP780 (1.2MM)	50	Weld or HAZ
SM-DT-2: DP980 (1.2MM) + DP980 (1.6MM)	74	Weld or HAZ
DM-DT-4: DP1180 (1.4MM) + DP780 (1.2MM)	104	Weld or HAZ

Major True Strain at Necking





KEY TAKEAWAYS

- LWBs showed reduced formability compared to the base metals
  - 7~36% for the uniaxial tension
  - 23~52% for the plane strain
- Micro-hardness testing is useful to measure hardness variation and softening of the HAZ (hardness drop) for the DP steel.
- Two formability testing methods are recommended to characterize the formability of LWBs:
  - Total elongations of both horizontal and vertical weld tensile tests with DIC
  - Maximum dome height and major strain limit of the plane-strain forming with DIC
- Enhanced prediction capability of the LWBs and material databases will assist designers in implementing LWBs for automotive structural applications.

FOR MORE INFORMATION

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More Questions? Meet Hyunok at the Auto/Steel Partnership booth after this presentation.