AET INTEGRATION

Investigation of GMAW Heat-Affected Zone Fatigue Performance of AHSS and Mild Steel

Justin Hunt
Chonghua Jiang
Jessica Sun
AET Integration

Background

- Previous AISI fatigue studies have shown DP780 to have superior fatigue performance compared to mild steel for “improved” GMAW welds.

- For welds with high stress concentrations at the weld toes (small toe radius), mild steel and DP780 weld fatigue performance was very similar.

- Typically, DP780 welded joints failed in the HAZ at the weld toes, indicating that geometry improvements could increase fatigue life. Mild steel welds generally failed through the weld metal at the weld root, where little improvement in geometry can be made.

Background

- Heat-affected zone (HAZ) softening or (hardening in some cases), which is considered a metallurgical notch, is inevitable for most of the AHSS.

- How will metallurgical notches, compared to physical notches, impact fatigue life of AHSS GMAW joints?

Common Weld Fatigue Perceptions

Higher strength base metal means better fatigue strength of welded joints?

Once welded, all steels will have equal fatigue performance?

Fatigue strength depends on the degree of HAZ softening?

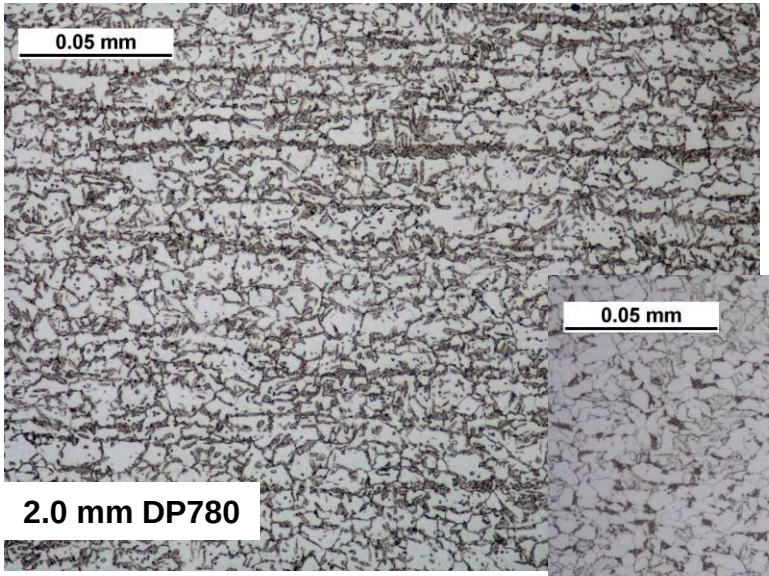
Objective

- To explore the effects of metallurgical and physical notches on fatigue life of AHSS.

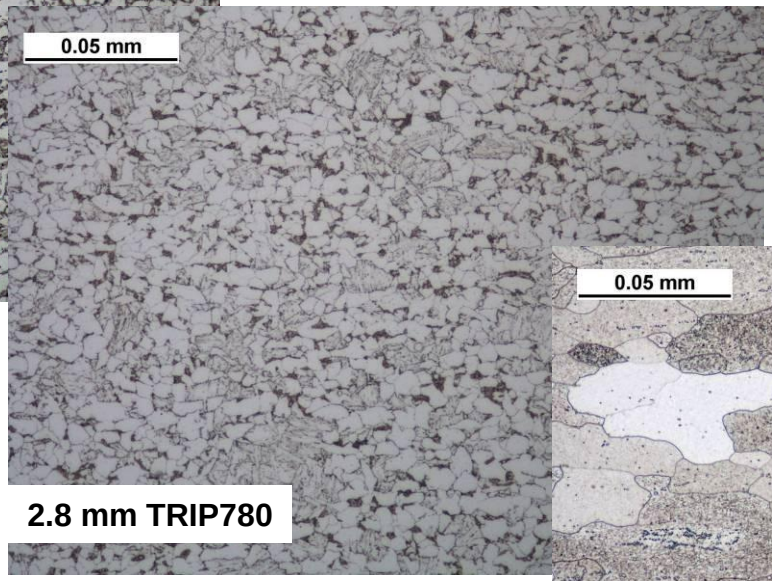
Materials

- 2.0 mm DP780
- 2.8 mm TRIP780
- 2.0 mm Mild Steel
- All uncoated

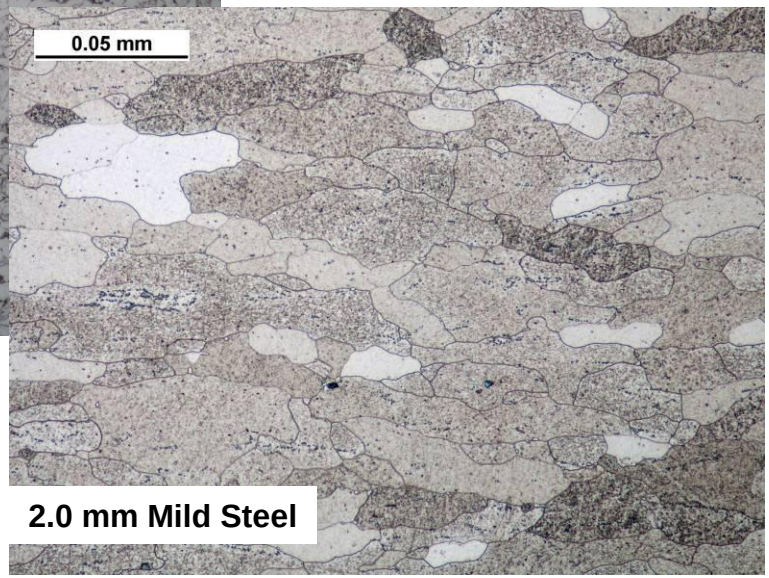
Base Metal Microstructures



2.0 mm DP780



2.8 mm TRIP780

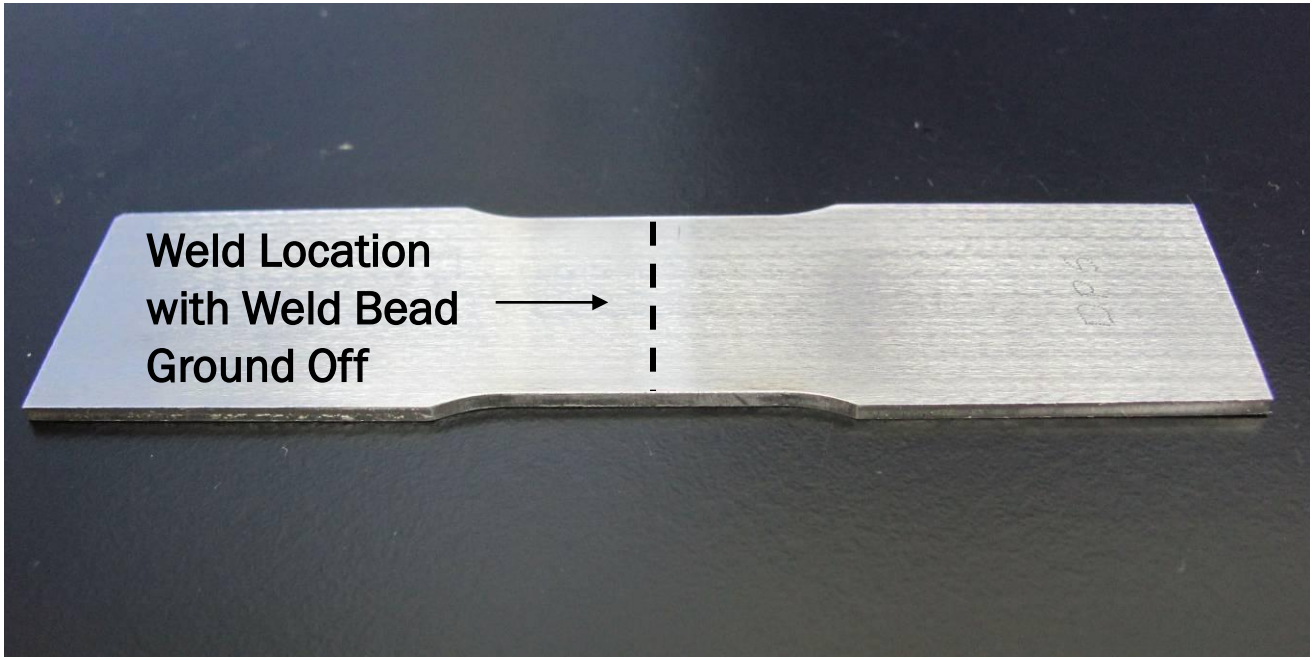


2.0 mm Mild Steel

Approach

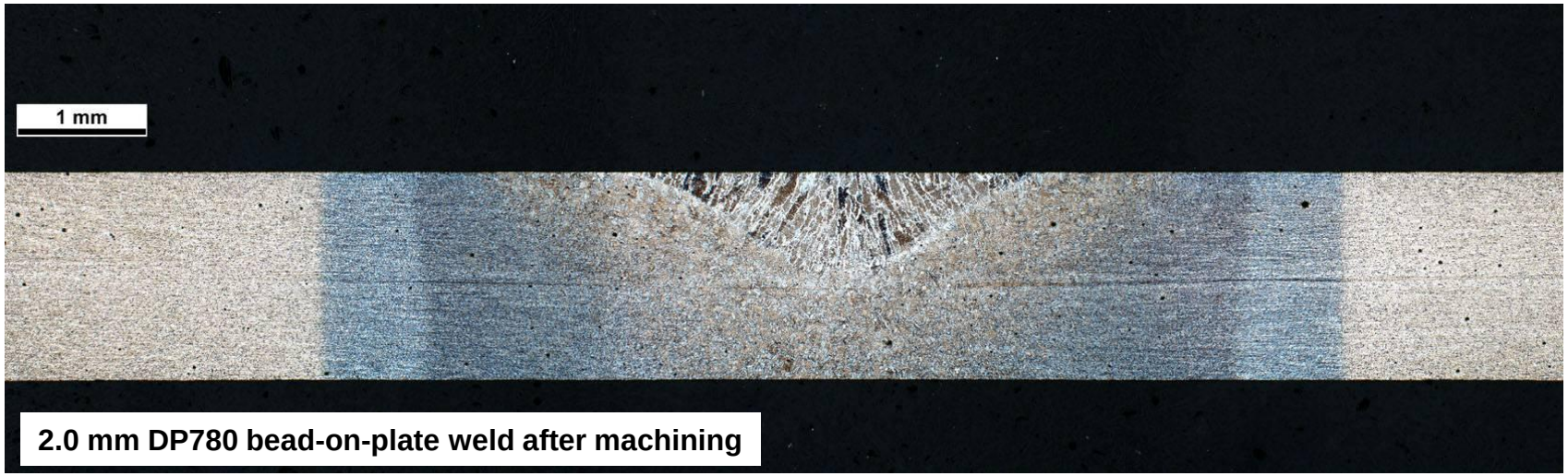
- Bead on plate welds were made on 4”x12” plates and cut into 1” wide strips.
- Both top and bottom surfaces of the strips were ground to uniform thickness specimens to eliminate the influence of weld geometry on stress concentrations.
- Ground specimens were etched to show HAZ and weld metal.
- Weld metal, coarse grained HAZ and intercritical HAZ were located under 10X magnification and physical notches were made at the desired location.
- Fatigue testing was conducted on specimens with and without physical notches.

Effect of Metallurgical Notches

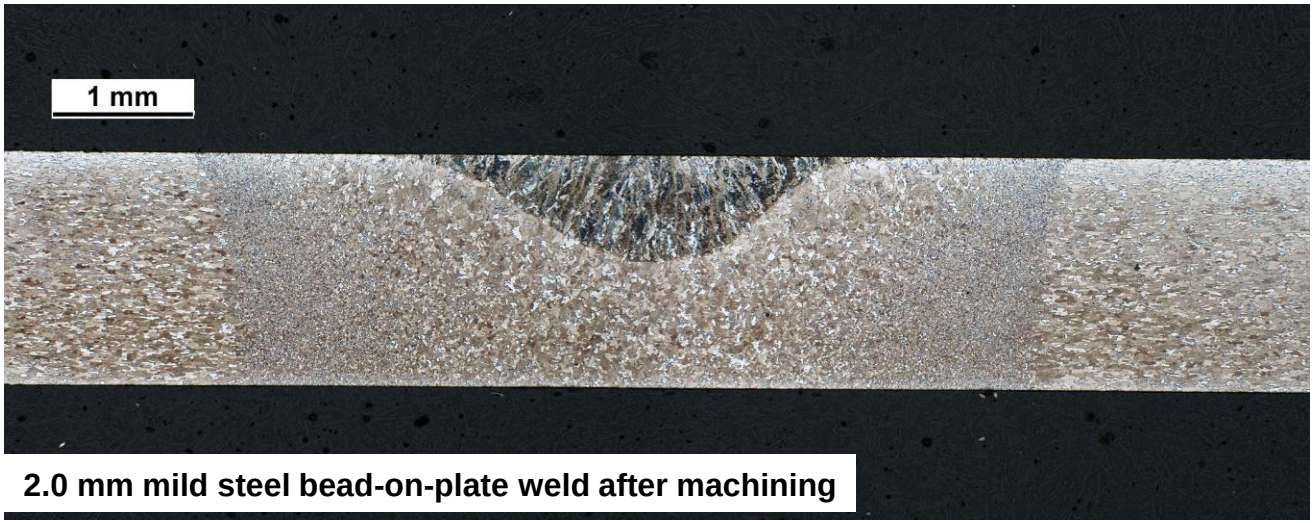


Fatigue Specimen with Metallurgical Notch Only

Effect of Metallurgical Notches

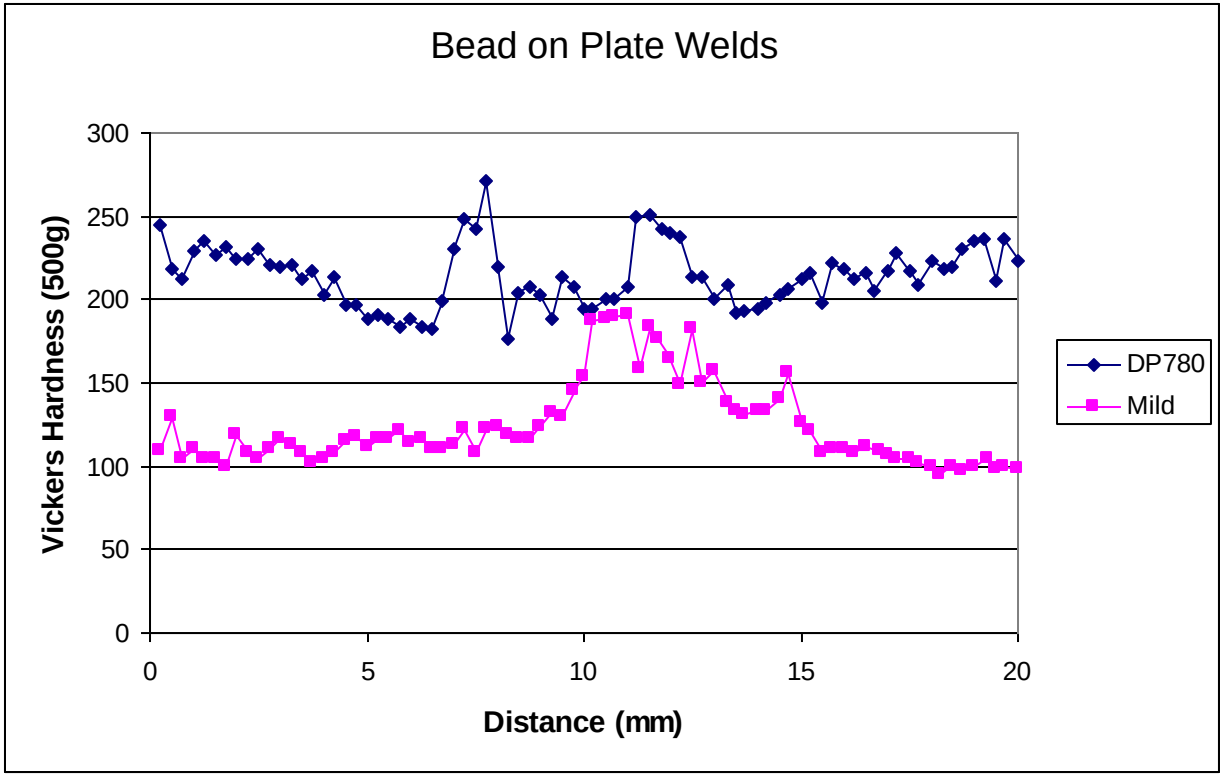


2.0 mm DP780 bead-on-plate weld after machining



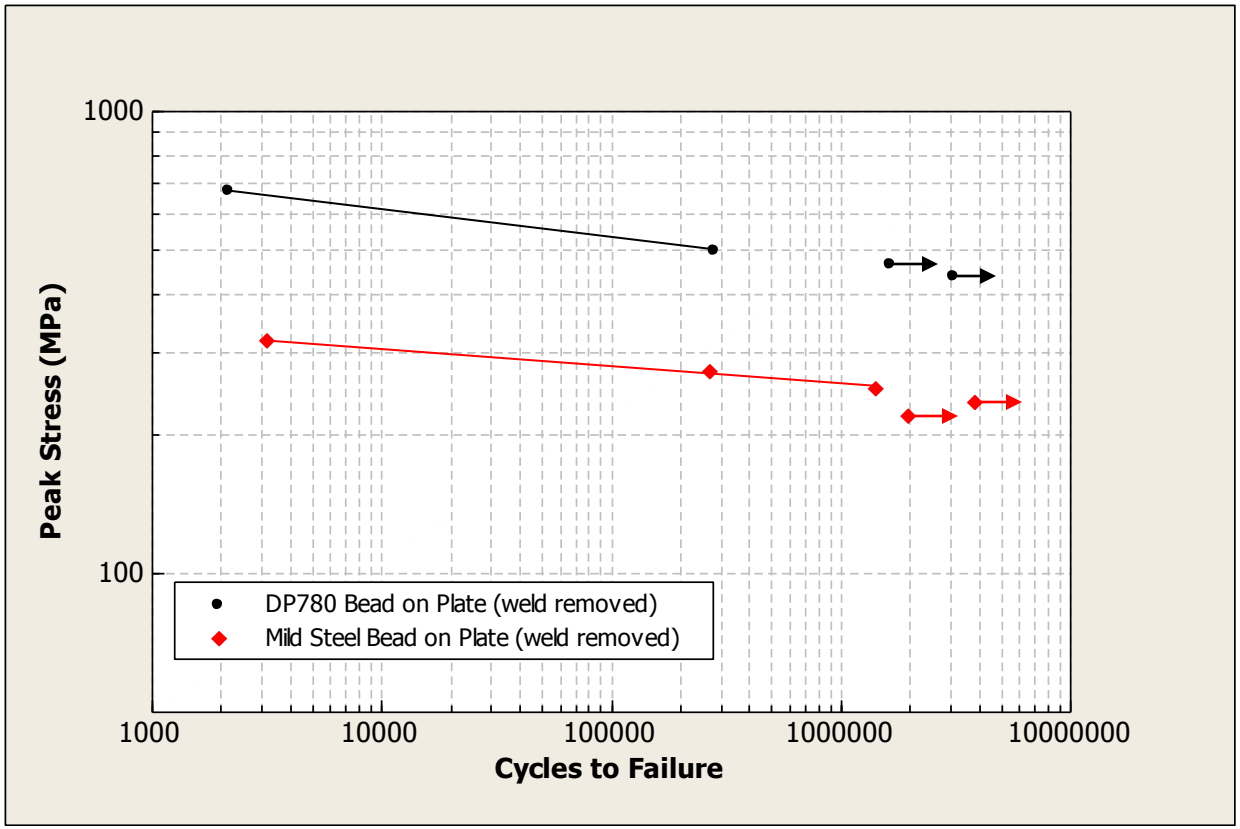
2.0 mm mild steel bead-on-plate weld after machining

Effect of Metallurgical Notches



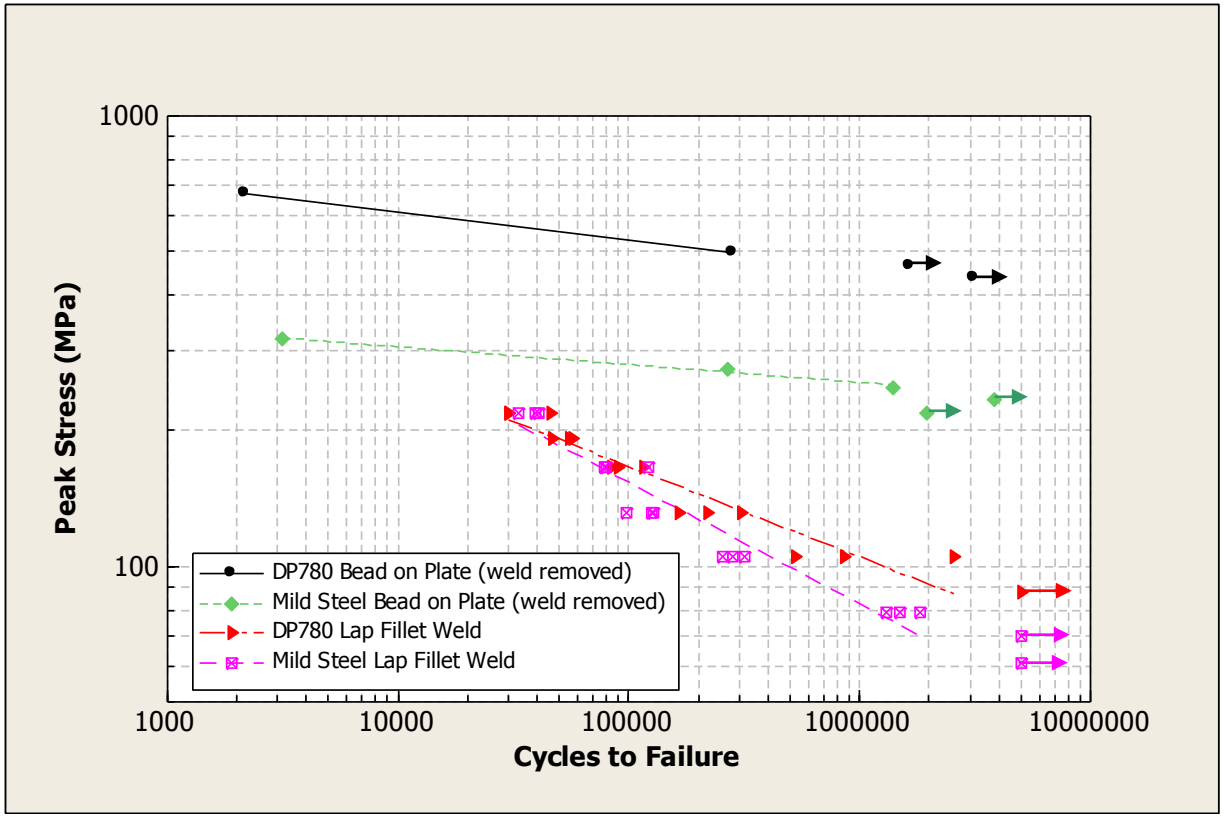
- HAZ softening was approximately 22% for DP780
- The lowest microhardness value in HAZ of DP780 is about 1.4 times that of mild steel

Effect of Metallurgical Notches



Mild Steel and DP780 Bead on Plate Weld (Metallurgical Notches only)

Effect of Metallurgical Notches



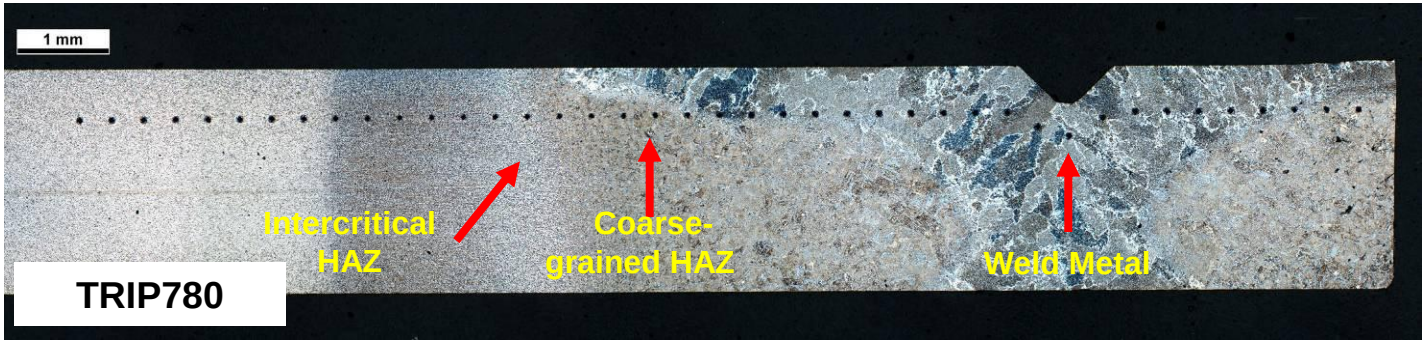
Mild Steel and DP780 Bead on Plate and Lap Fillet Welds*

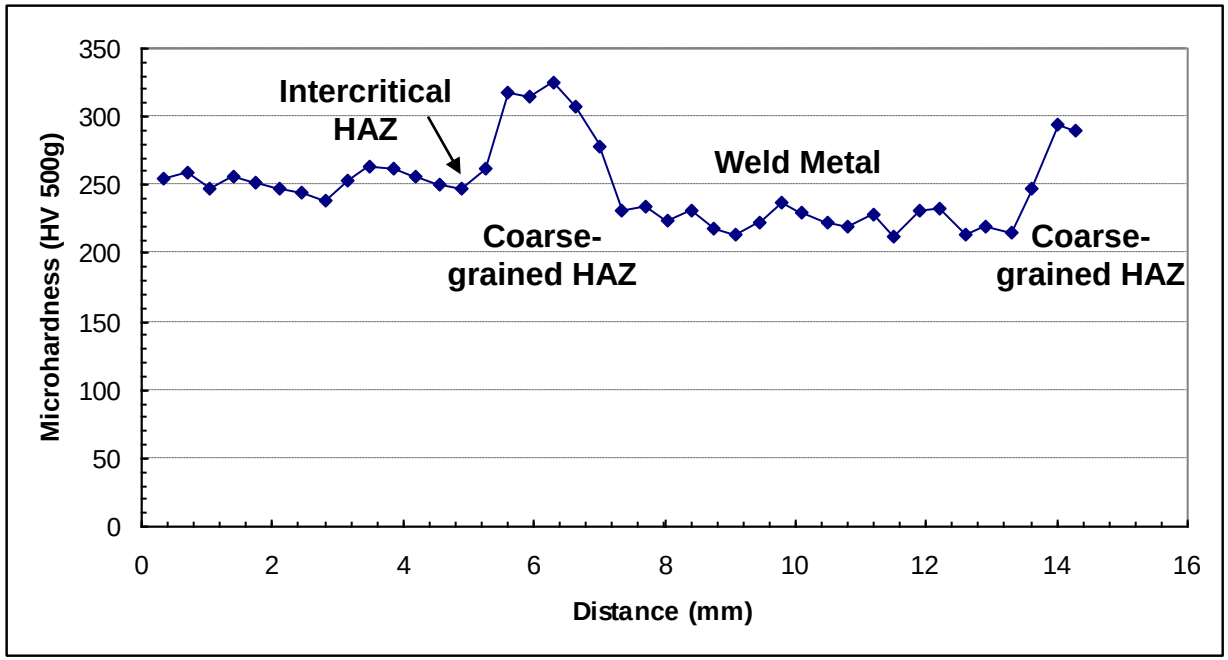
*Lap fillet weld data from work sponsored by AISI

Effect of Metallurgical Notches

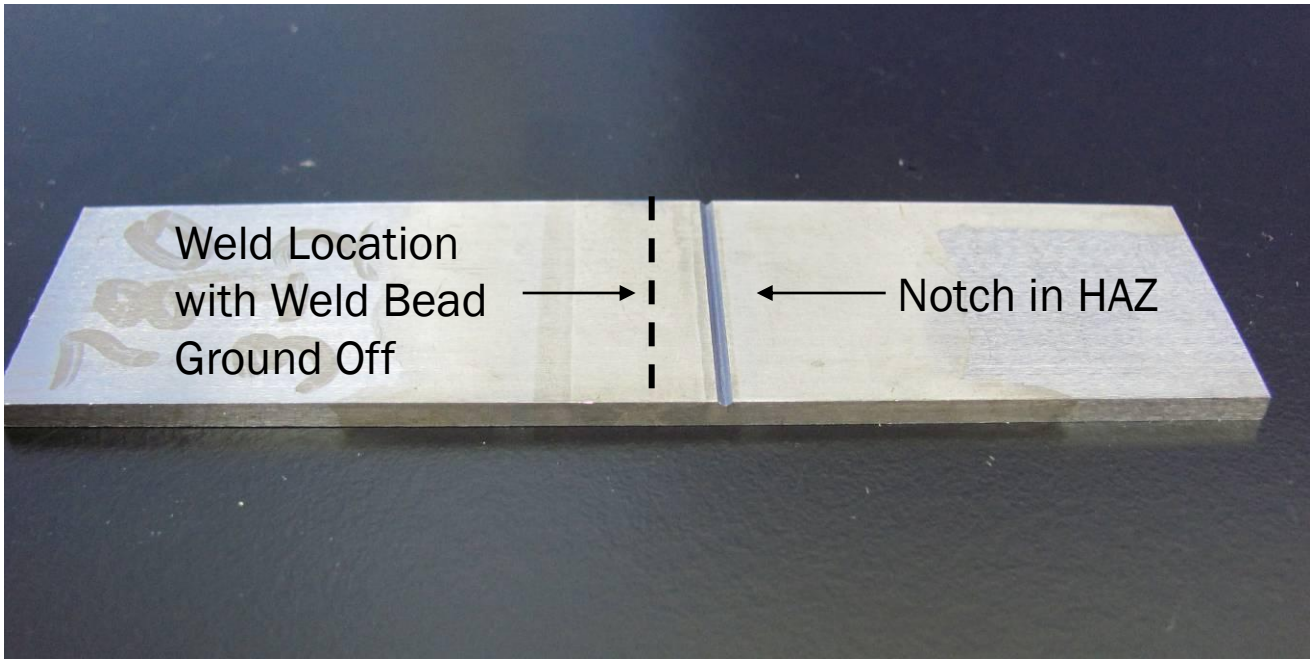
- After welding, the tensile strength of DP780 was approximately 2.1 times higher than mild steel for bead on plate specimens.
- It appears that the run-out stress of DP780 is approximately 2 times higher than mild steel for bead on plate specimens.
- This indicates that the reduction of fatigue life for lap fillet welds is due primarily to weld geometry effects.

Effect of Physical Notches





Effect of Physical Notches (TRIP780)

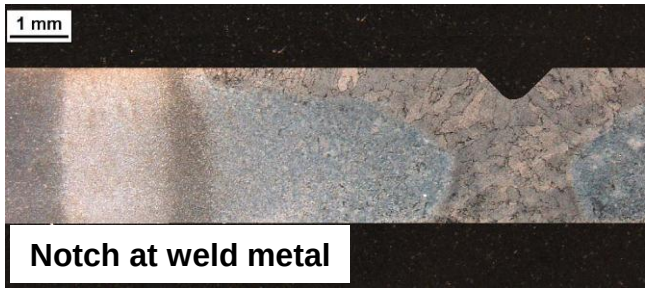


Fatigue Specimen with Physical Notch

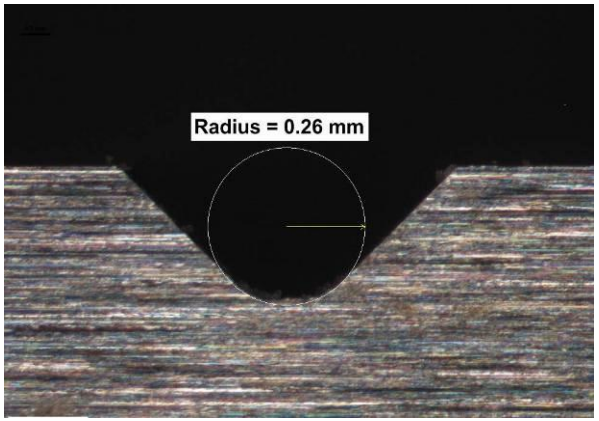
Physical Notch Placement

Notch at intercritical HAZ

Notch at coarse-grained HAZ

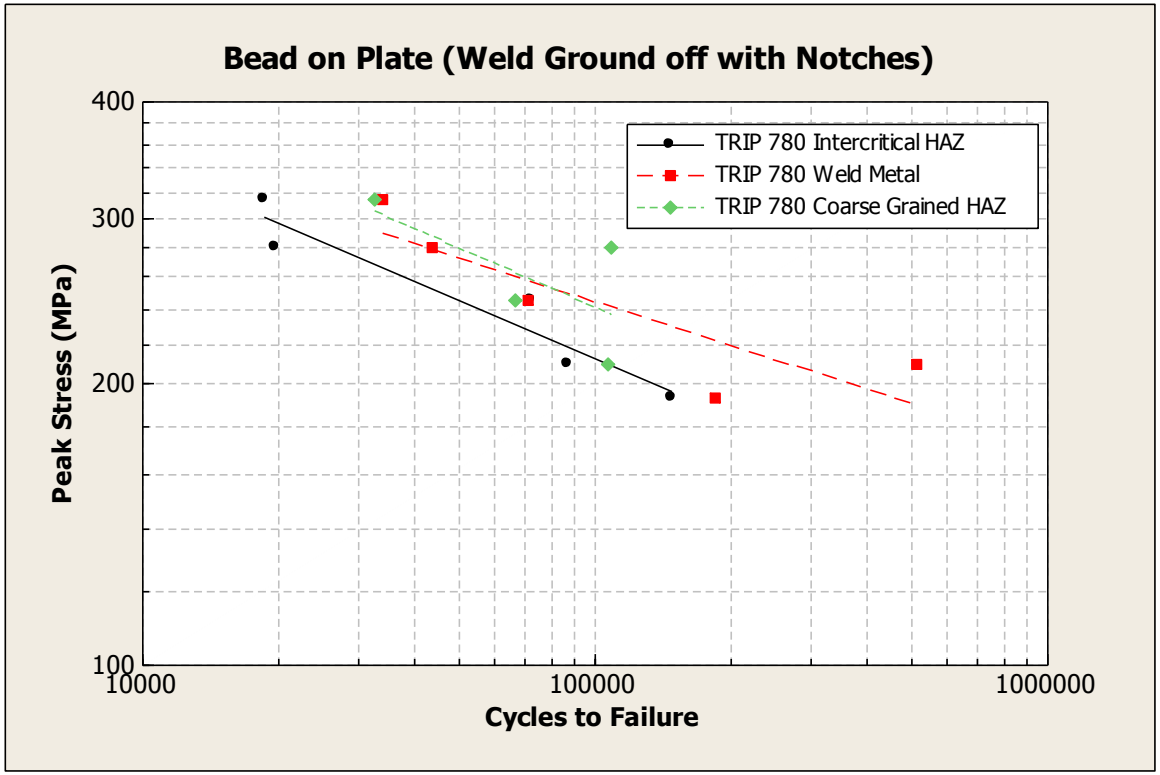


Notch at weld metal



Cross-section of as-welded TRIP780

Effect of Physical Notches



TRIP780 HAZ and Weld Metal Fatigue
(with both metallurgical and physical notches)

Effects of Local Geometry and Material Strength on Fatigue Life

$$N_{total} = N_i + N_p$$

$$N_p = \frac{1}{C}\int_{a_0}^{a_c} \frac{da}{\left(\Delta S\sqrt{\pi a}F(a)\right)^m}$$

$$N_i = \frac{1}{2}\left[\frac{2\left(\sigma_f' - \sigma_m\right)}{K_f \Delta S}\right]^{-1/b}$$

$$K_f = 1 + \frac{K_t - 1}{1 + a_p/\rho}$$

$$K_t = 1 + 0.5121\theta^{0.572}\left(\frac{T}{\rho}\right)^{0.469}$$

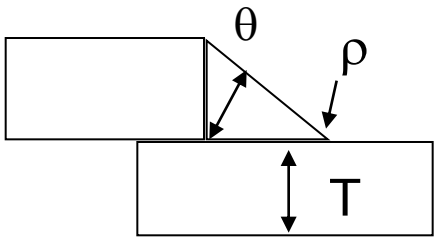
Paris law for propagation

Coffin-Manson Equation for initiation

$$b = -0.1667\log\left(2.1 + \frac{917}{S_u}\right)$$

$$\sigma_f' = 0.95S_u + 370MPa$$

$$a_p = 1.187x10^5/S_u$$



N_i: initiation life

N_p: propagation life

ΔS: nominal stress range

K_t: stress concentration factor

K_f: Fatigue notch factor

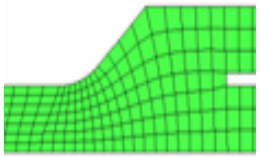
Su: ultimate strength

After: P. Darcis et al, 2006

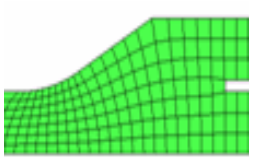
F. Lawrence et al. 1995

Improvement of Weld Profile May Particularly Benefit AHSS

A
Toe Angle: 45°
Toe Radius: 1.0mm



B
Toe Angle: 30°
Toe Radius: 2.5mm



Improvement in Kf	Improvement in Crack Initiation Life	
	Mild (300MPa)	DP780
5%	151%	176%
10%	223%	302%
20%	463%	829%
30%	906%	2098%
40%	1688%	4955%
50%	3014%	11032%

Improvement from A to B for 2.0mm DP780 would improve K_f by 17% or fatigue life by 6.5 times

Effect of Physical Notches

- No clear trend was observed for the TRIP780 bead-on-plate specimens with both metallurgical and physical notches.
- It appears that the intercritical HAZ may show slightly lower fatigue strength than the weld metal and coarse grained HAZ.
- AET is currently conducting testing on TRIP780 bead-on-plate specimens with metallurgical notches only.

Effect of Physical Notches

- Preliminary results showed that bead-on-plate specimens can be used for fundamental understanding of fatigue life of AHSS GMA welds.
- It appears that the run-out stress of DP780 is approximately 2 times higher than mild steel for bead on plate specimens, which indicates that the reduction of fatigue life for lap fillet welds is due primarily to weld geometry.
- If weld geometry could be further improved, it is likely that fatigue life could be much higher in DP780.
- More research needs to be conducted on metallurgical notches and physical notches to better understand fatigue life of AHSS welds.

Thank You!

For more information contact:

Justin Hunt
Senior R&D Engineer
AET Integration
(248)313-3032
justin.hunt@aet-int.com