GREAT DESIGNS IN STEEL

EFFECT OF BAKE-HARDENING ON BASE METAL AND POST-WELD PROPERTIES OF 3RD GENERATION AHSS

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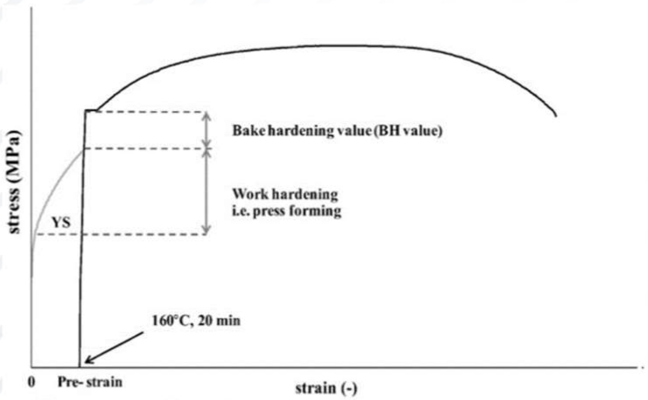
GENERAL OUTLINE

- Introduction to Bake-Hardening
- Base metal properties after uniaxial pre-straining and bake-hardening in two 3G-AHSS grades
- Comparing post-weld properties before and after bake-hardening in 3G-AHSS grades

INTRODUCTION TO BAKE-HARDENING

- The increase in yield strength after stamping and paint-baking.

- The interstitial carbon atoms in the substrate material diffuse to dislocation cores during paint-baking and pin the dislocations.



- The bake hardening index (BHI) or value is calculated by measuring the (lower) yield stress after pre-straining and paint-baking and subtracting the flow stress measured at that given pre-strain

- The bake hardening (BH) effect is traditionally dependent on the amount of interstitial carbon available in the ferrite matrix and dislocation density [1]

[1] A. Van Snick et al. Proc. Conf. On "Modern LC and ULC sheet steels for cold forming: processing and properties", 1998

INTRODUCTION TO BAKE-HARDENING

- For more complex microstructures, a number of additional factors have also been reported to contribute to the BH response
  - the ferrite grain size [1][2] and overall microstructure grain size
  - volume fraction and morphology of phases before treatment [3][4]
  - the stress partitioning between phases during pre-straining [5]
- BH has been studied to some degree in 1st generation AHSS (TRIP and DP)
- In 3rd generation AHSS, the complexity of the microstructure has increased and the BH behavior is unknown

[1] T. Obara et al. Kawasaki Steel Technical Report, 1985
[2] K. Eloot et al. ISIJ International, 1998,
[3] W.S. Li et al. Materials Science & Engineering A, 2016,
[4] C.H. Song et al. Materials Science & Engineering A, 2016
[5] W.S. Li et al. Materials Characterization, 2016

BASE METAL PROPERTIES AFTER UNIAXIAL PRE-STRAINING AND BAKE-HARDENING

MATERIALS AND METHODS

Grade	Thickness (mm)	YS (MPa)	TS (MPa)	TE (%)
CR980 HF	1.2	742	1077	21
CR1180 HF	1.2	922	1279	14

- ASTM L and T uniaxial tension specimens were fabricated from both grades
- Specimens were subjected to:

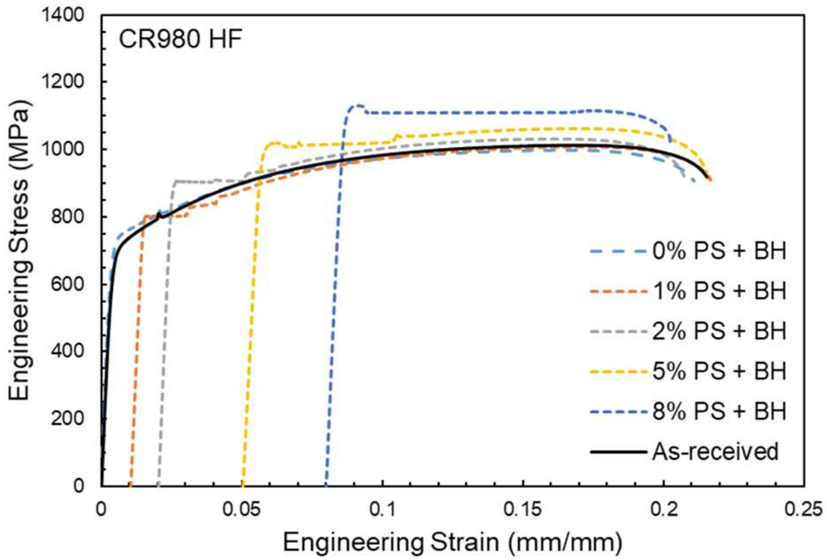
  0 / 1 / 2 / 5 / 8 / 10% uniaxial pre-strain

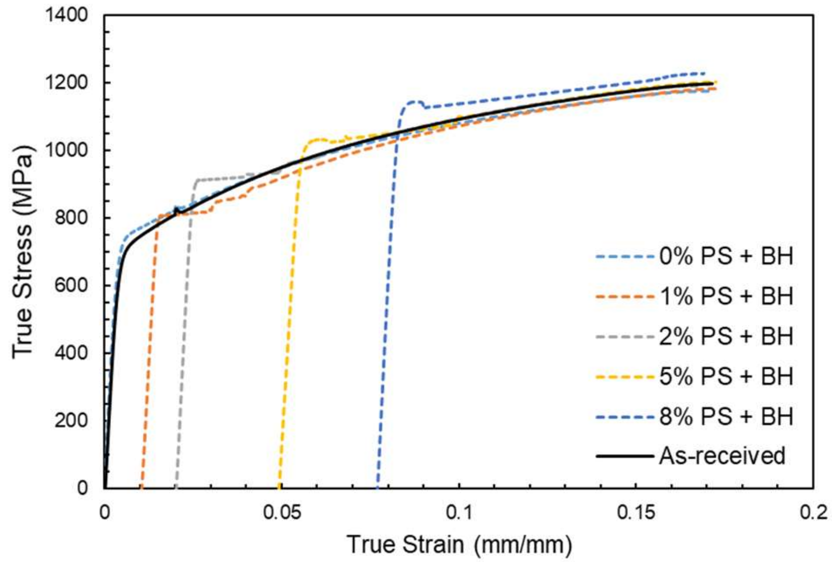
- After pre-straining, specimens were baked for:

  170 °C for 20 minutes

- Results are the average of at least two tests per condition

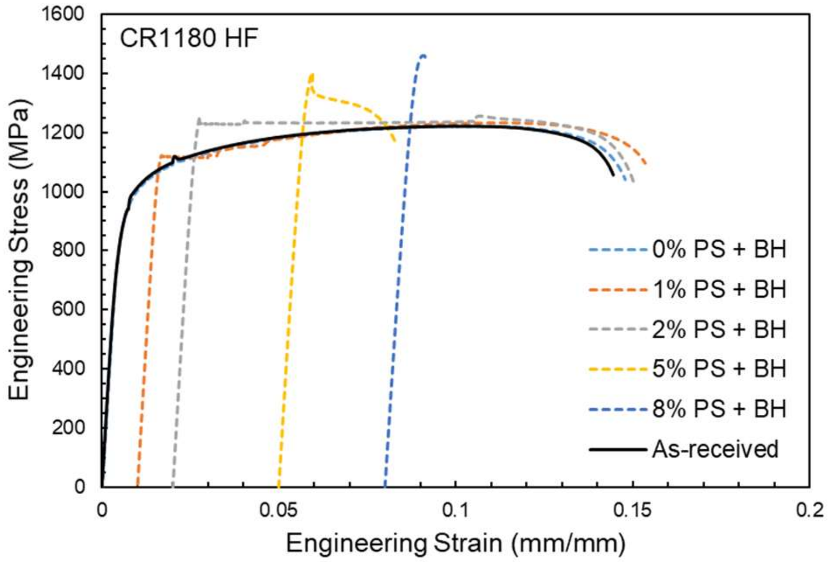
BAKE-HARDENING IN CR980 HF

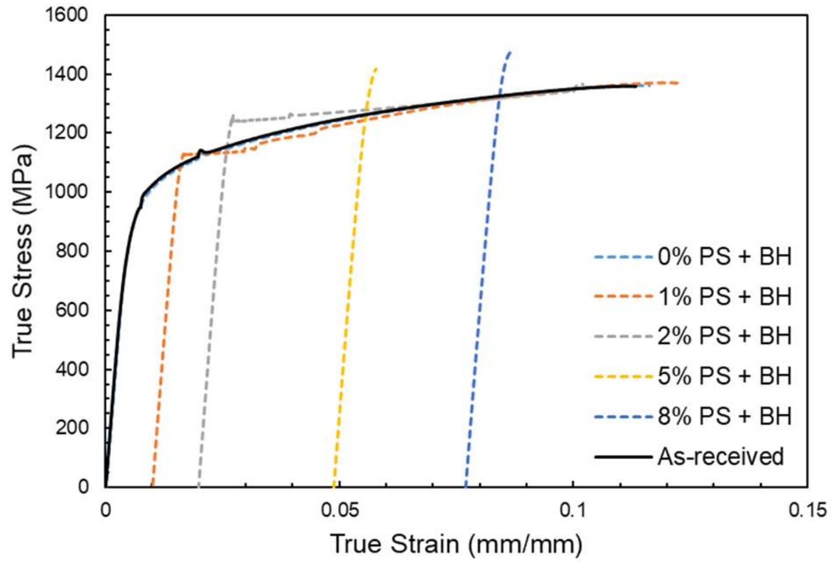




- Increase in YS and TS with increasing pre-strain and bake-hardening
- Change in work-hardening behavior, appearance of upper yield point

BAKE-HARDENING IN CR1180 HF





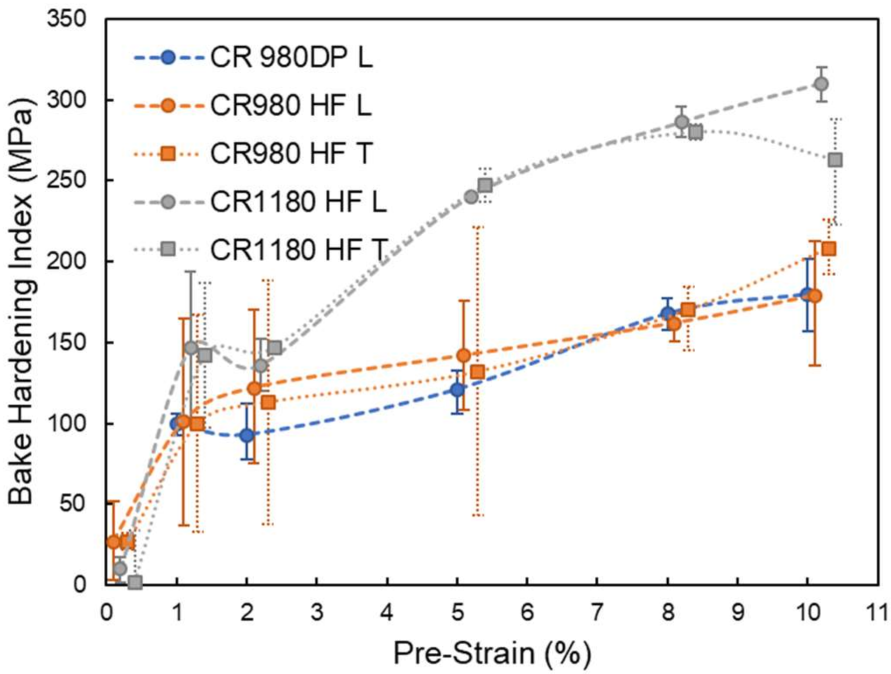
- Increase in YS and TS with increasing pre-strain and bake-hardening
- Change in work-hardening behavior, transition at PS between 2 and 5%

BAKE-HARDENING INDEX (BHI)

The bake-hardening effect was observed in both L and T directions and was relatively isotropic

The magnitude of the BHI was:

- Comparable between CR980 HF and CR980 DP (100-150 MPa)
- Significantly greater in CR1180 HF (ranging from 150-300 MPa)



The BHI was observed to:

- Increase in CR980 HF with increasing pre-strain level
- Increase in CR1180 HF with a significant increase observed between 2 and 5% PS

SUMMARY

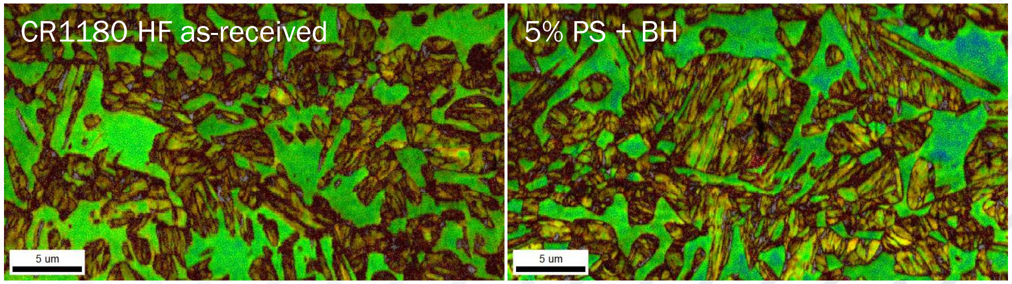
- Bake-hardening was studied in two 3rd Generation AHSS grades
  - BH not only increased the YS, but also the TS and work-hardening behavior

- The bake-hardening index exhibited complex behaviors with increasing pre-strains studied between 1 – 10%

- These observations are critical for modeling of stamping and performance of these 3rd Gen AHSS, which rely on accurate stress-strain behaviors and material cards

On-going work - what role does the microstructure play?

- XRD has shown no change in ret. austenite content before and after bake-hardening
- EBSD kernel average misorientation (KAM) maps have shown changes in different phases which remains to be studied further



POST-WELD PROPERTIES BEFORE AND AFTER BAKE-HARDENING

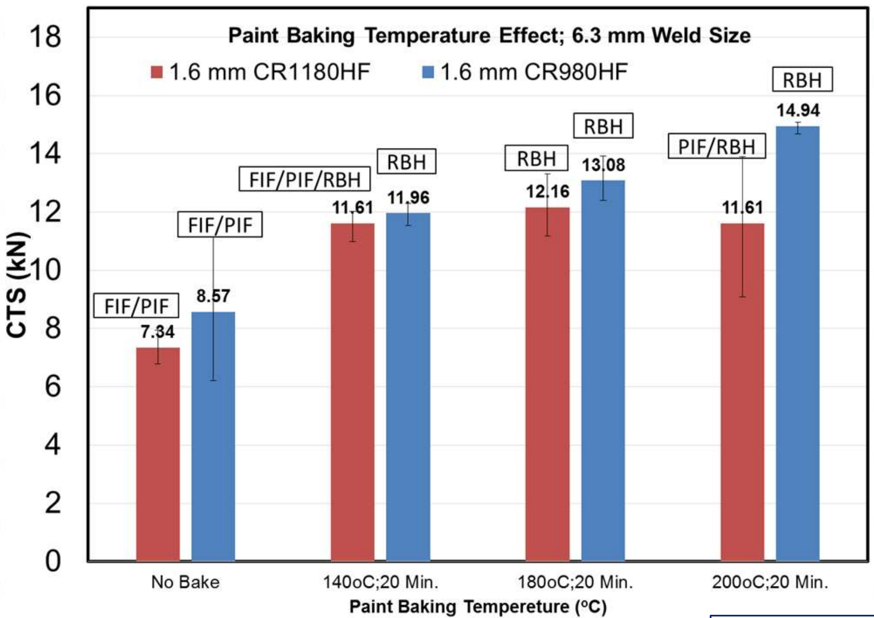
WELDING CONDITION AND SCHEDULES

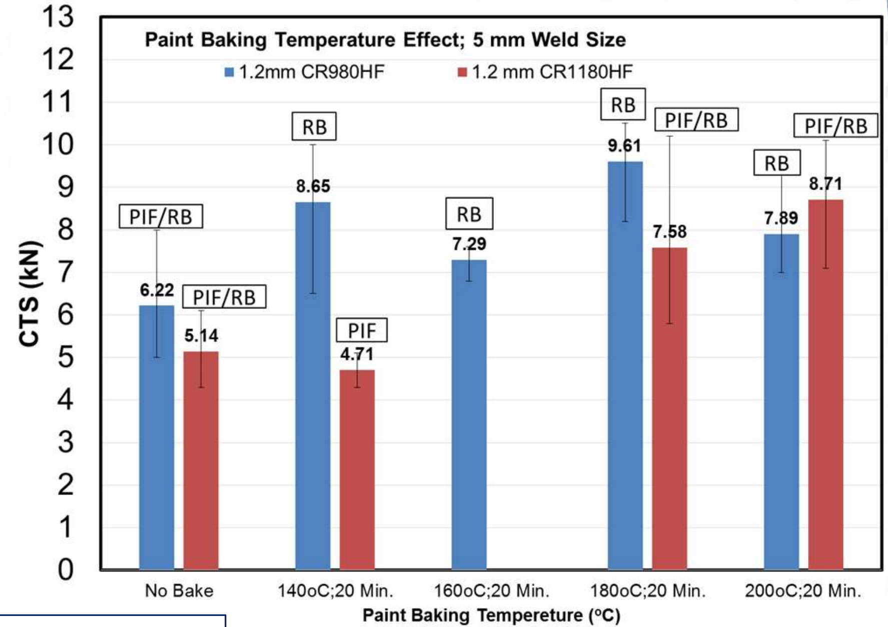
Welding Schedule #	Studied Materials		Force (kN)	Pulse # (Cyc.)	Cooling (Cyc.)	Short Pulse	Holding (Cycles)	CP / CT/TS	Paint Baking
	CR980HF	CR1180HF							
1	1.2 mm 1.6 mm	1.2 mm 1.6 mm	3.6	2 (7)	1	No	15	CT/C P/TS	Yes
2	1.2 mm	NA	2.6	1 (10)	--	No	15	CT	Yes
3	1.2 mm 1.6 mm	1.2 mm 1.6 mm	4.9	2 (12)	2	No	10	CT	Yes
4	1.2 mm 1.6 mm	1.2 mm 1.6 mm	4.9	1 (18)	--	No	10	CT	Yes
5	1.2 mm 1.6 mm	1.2 mm 1.6 mm	4.9	1 (18)	--	5C-3W-2C-3W*	10	CT	Yes
6	1.2 mm 1.6 mm	1.2 mm 1.6 mm	4.9	1 (18)	--	5C-3W-2C-3W**	10	CT	Yes
7	1.2 mm	NA	4.9	1 (18)	--	15C-3W-2C-3W*	10	CT	Yes
8	1.2 mm	NA	4.9	1 (18)	--	15C-3W-2C-3W**	10	CT	Yes

- W: Welding
- C: Cooling
- *80% of welding current
- ** 120% of welding current

- Mode: MFDC
- Electrode: Dome; 6mm
- Flow rate: 6 l/min

CROSS-TENSION STRENGTH - BAKING TEMPERATURE EFFECT
CR980HF AND CR1180HF



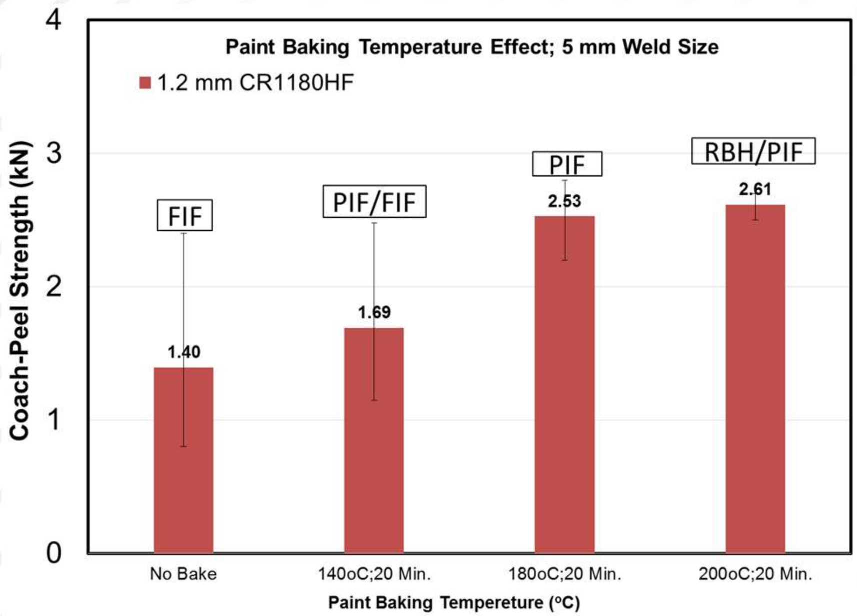


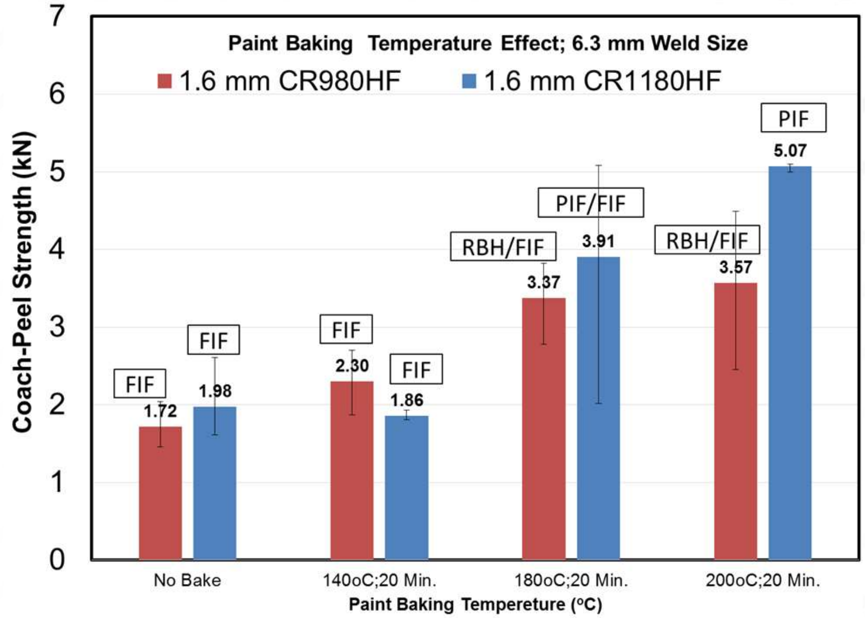
Welding Schedule # 1

- Cross-tension strength improves after paint baking.
- Change in failure modes from FIF --> RBH after paint baking
- Increase in temperature enhances improvement, and less temperature effect above 180°C.

- FIF: Fully Interfacial Failure
- PIF: Partial Interfacial Failure
- RB: Round Button
- RBH: Round Button HAZ

COACH-PEEL STRENGTH – BAKING TEMPERATURE EFFECT
CR980HF AND CR1180HF





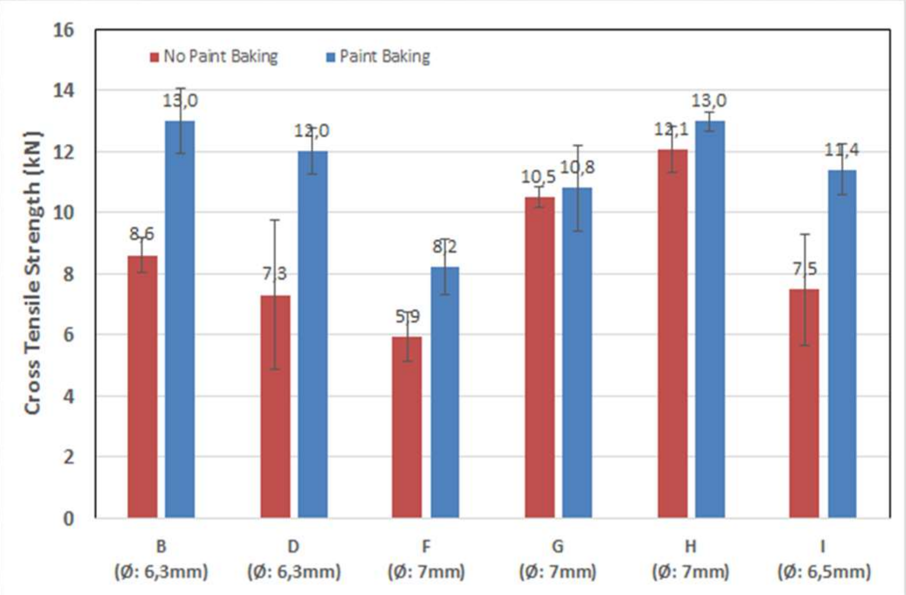
Welding Schedule # 1

- Significant effect of paint baking cycle on coach-peel strength of CR980HF and CR1180HF.
- Change in failure mode helps for improvement of peel strength.
- Increase in temperature enhances improvement, and less temperature effect above 180°C.

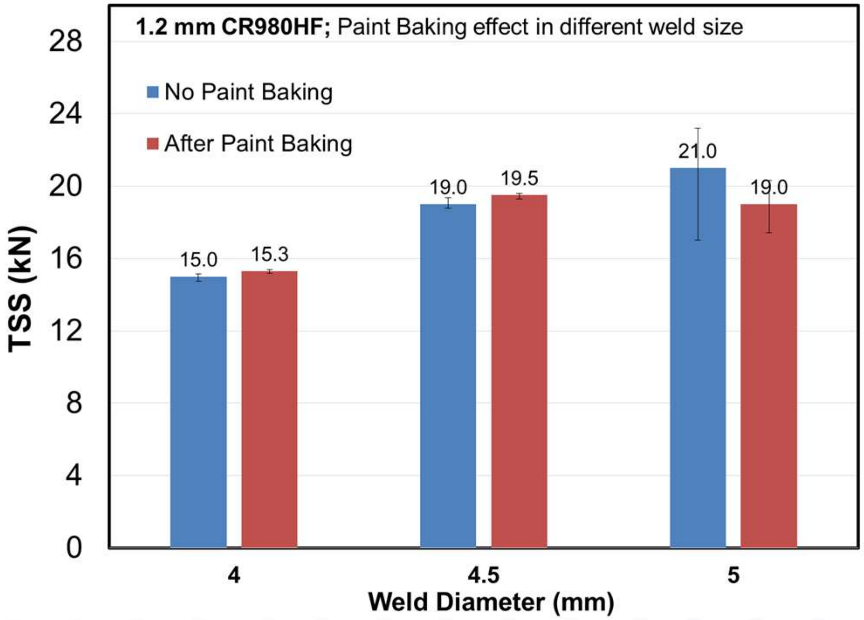
- FIF: Fully Interfacial Failure
- PIF: Partial Interfacial Failure
- RB: Round Button
- RBH: Round Button HAZ

WHERE PAINT BAKING DOESN'T AFFECT SPOT-WELD STRENGTH?

Grade Effect; Courtesy of SMWC 2018 Paper*



Tension-Shear Strength

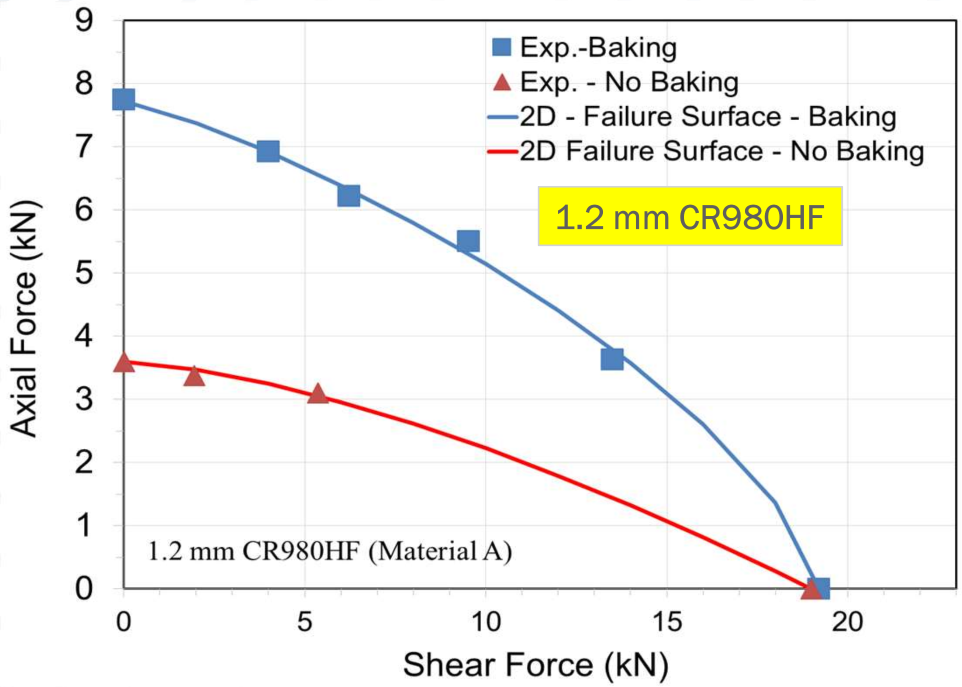


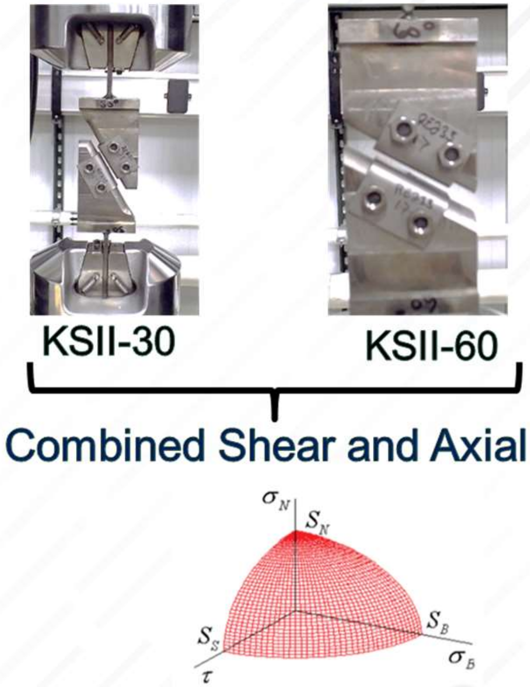
Material Label	Grades	Sheet Thick. (mm)	Nominal UTS (MPa)
B	Gen. 3	1.6	980
D	Gen. 3	1.6	1180
G	Gen. 1	1.5	980
H	Gen. 1	1.6	1180
I	Gen.3	1.6	1180

- No improvement of weld toughness after paint baking for
  - Tension-Shear loading modes
  - Dual-Phase and Martensitic grades; Generally Non-TRIP Effect grades

* H. Ghassemi-Armaki and et al., *"Improvement of Weld Strength and Toughness after Paint Baking in 3rd Gen. AHSS", AWS Sheet metal Welding Conference XVIII; OCT. 2018*

COMBINED AXIAL/SHEAR LOADING MODES





- KSII are the combined loading modes of shear and axial forces, representative of the most loading modes during crash for spot-welds.
- Improvement of weld strength and toughness after baking is apparent for KSII.
- *Improvement of weld strength is more pronounced when loading mode is dominant by axial force and less effective close to pure shear loading modes.*

WELDING CONDITION AND SCHEDULES

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Welding Schedule #	Studied Materials		Force (kN)	Pulse # (Cyc.)	Cooling (Cyc.)	Short Pulse	Holding (Cycles)	CP / CT/TS	Paint Baking
	CR980HF	CR1180HF							
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- W: Welding
- C: Cooling
- *80% of welding current
- ** 120% of welding current

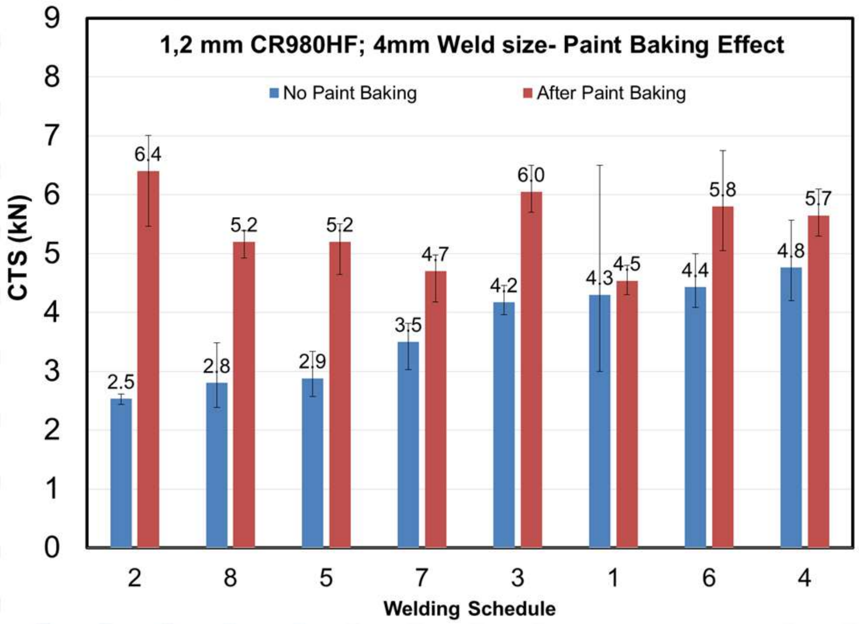
- Mode: MFDC
- Electrode: Dome; 6mm
- Flow rate: 6 l/min

CROSS-TENSION STRENGTH – WELD SCHEDULE EFFECT
1.2 MM CR980HF

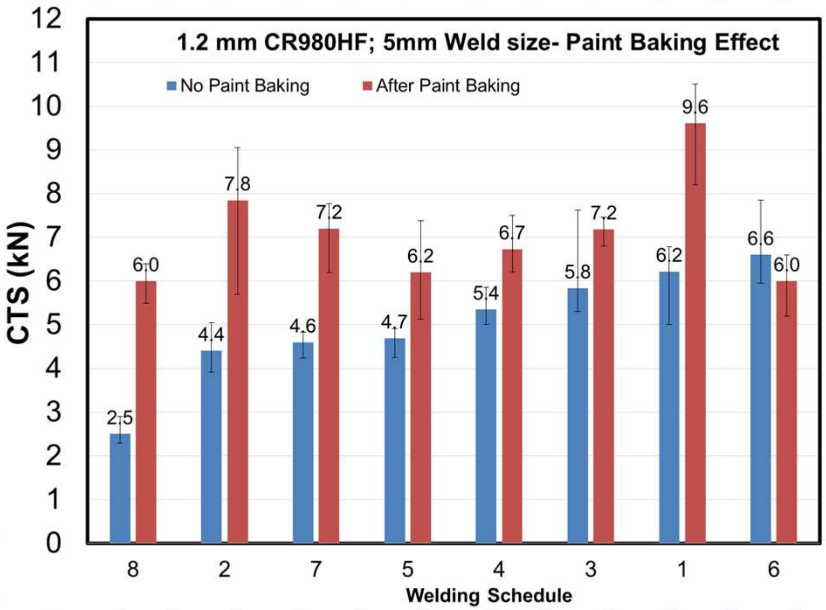
Simultaneous Effect of Welding Schedule and Bake Hardening;

Paint Baking: 180ºC; 20 min

4mm Weld Diameter

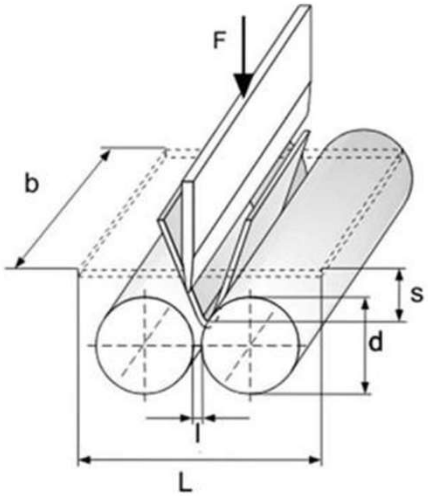


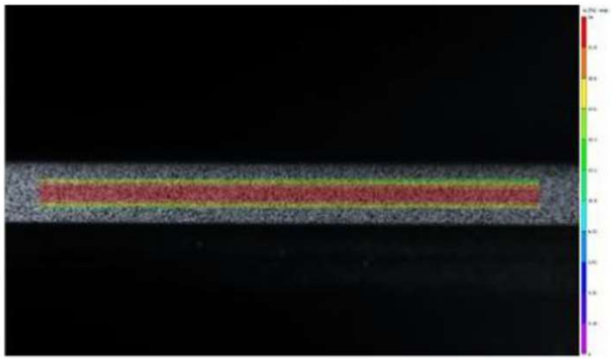
5mm Weld Diameter



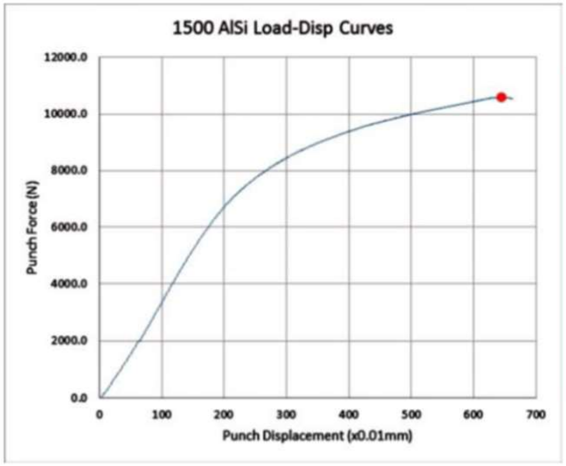
- There is effect of welding schedule on CTS
  - Not observed in the past for Martensitic, PHS and DP grades.
- Effect of welding schedule on CTS after paint baking is still apparent, but less!

VDA BENDING TEST ENHANCED WITH DIGITAL IMAGE CORRELATION

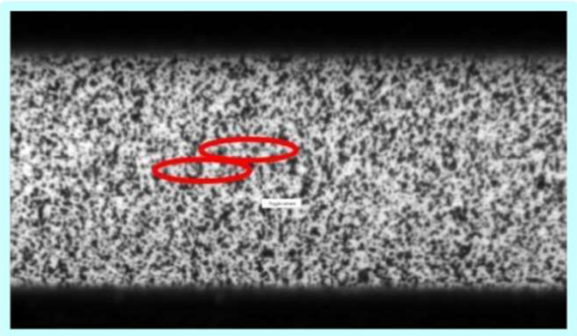




Punch Force vs Travel



Corresponding Picture with Cracks

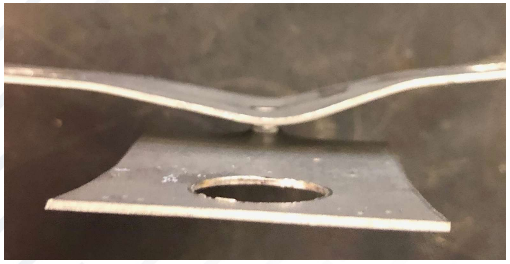


For VDA tests, the surface fracture strain is determined when the sample has experienced the maximum bend force/punch load

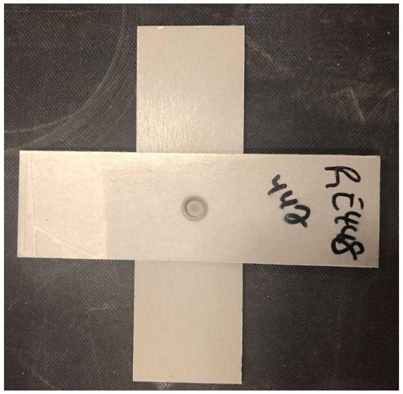
BENDING TEST IN WELDED SAMPLES –PAINT BAKING EFFECT

CR1180HF

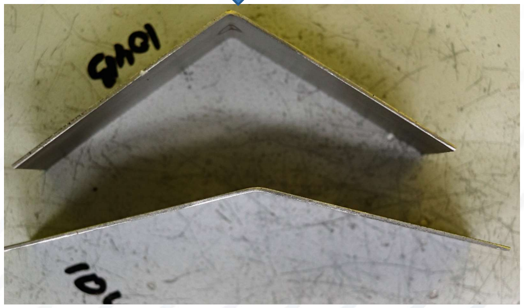
Cross-Tension After Loading/Failure

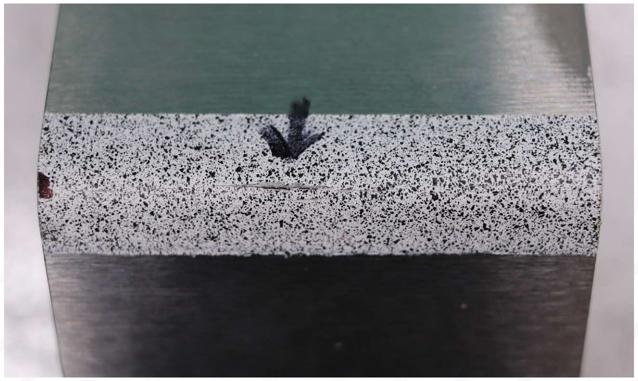


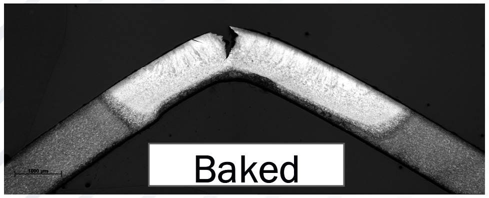
Rotation Shear Sample (To Simulate Loading during Mechanical test of spot-weld)

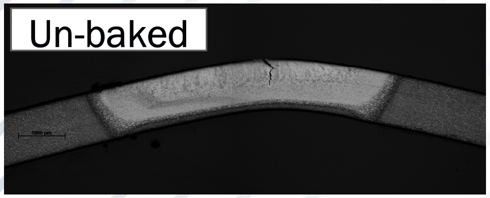


Single Samples After Rotation Shear

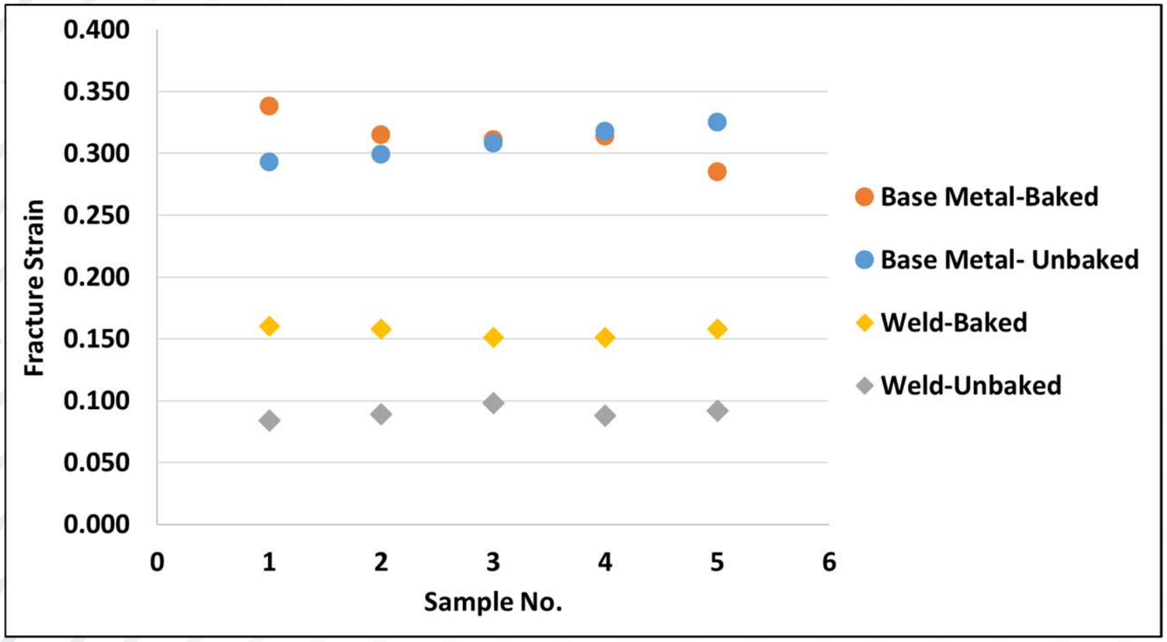








BENDABILITY IN WELDED SAMPLES –PAINT BAKING EFFECT
CR1180HF



Bending Angle	Unbaked	Baked
Base Metal	92.98	91.5
Welded Sample	41.14	55

- Fracture Strain and bending angle increase after baking for welded samples, but not for base metal.
- Contribution of HAZ in Spot-Weld can be the factor for improvement of fracture strain under bending mode for 3rd Gen. AHSS.

SUMMARY

- The cross-tension strength improves after bake-hardening
  - The failure mode changes from FIF to RBH after BH
- The increase in bake temperature enhances improvement of weld toughness
  - And there is less of a temperature effect above 180°C
- No improvement of weld toughness after BH was observed for:
  - Tension-Shear loading modes
  - Dual-Phase and Martensitic grades; Generally Non-TRIP Effect grades
- The effect of welding schedule on CTS after BH is still apparent, but less!

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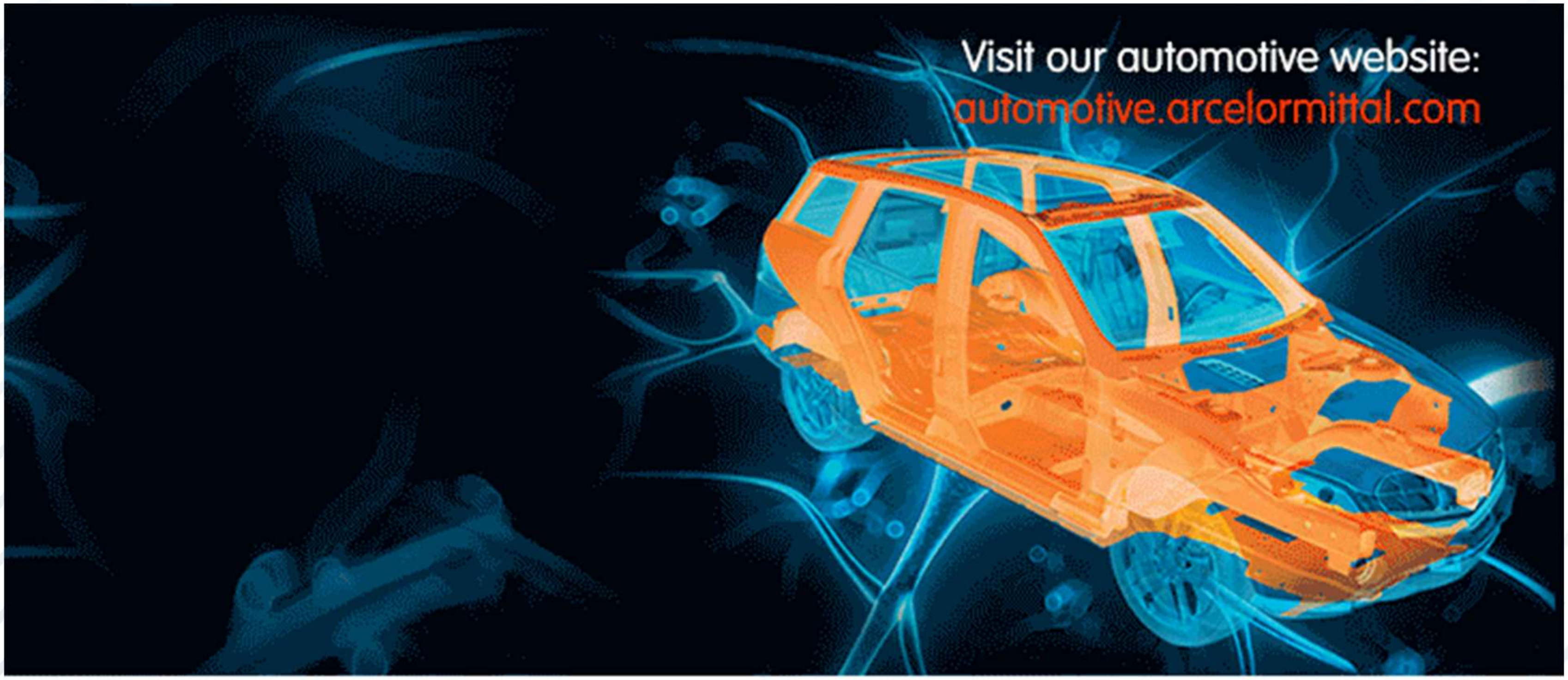
For More Information about ArcelorMittal Fortiform® grades:

https://automotive.arcelormittal.com/fortiform



Steel: the strongest choice

GREAT DESIGNS IN STEEL

Presentations will be available for download on SMDI's website on Wednesday, May 22