GREAT DESIGNS IN STEEL

LASER PROCESS MODIFICATION TO REDUCE CRATER CRACK IN ZN COATED 3RD GEN AHSS

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ACKNOWLEDGMENTS

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OUTLINE

- Overview and Background
- Laser Welding Development
  - Experimental Setup
  - Laser Welding Technologies (Single Spot, Twin-spot, and Wobble)
- Crater Crack Optimization
  - Surface Characterization and Aspect Ratio
  - Statistical Analysis of Improvement
- Understanding the Weld Microstructure
- Laser Weld Strength
  - Quasi-static Testing
  - Fatigue Testing
- Conclusions

OVERVIEW

Material

- The next generation of Advanced High-Strength Steels (AHSS) is considered for Body-in-White (BIW) applications to reduce the vehicle weight thereby improving fuel efficiency without compromising the vehicle safety.
- Fortiform® 980 GI is a new class of AHSS by ArcelorMittal developed to provide excellent formability and high strength for automotive parts which has been used in this study.

Welding Process

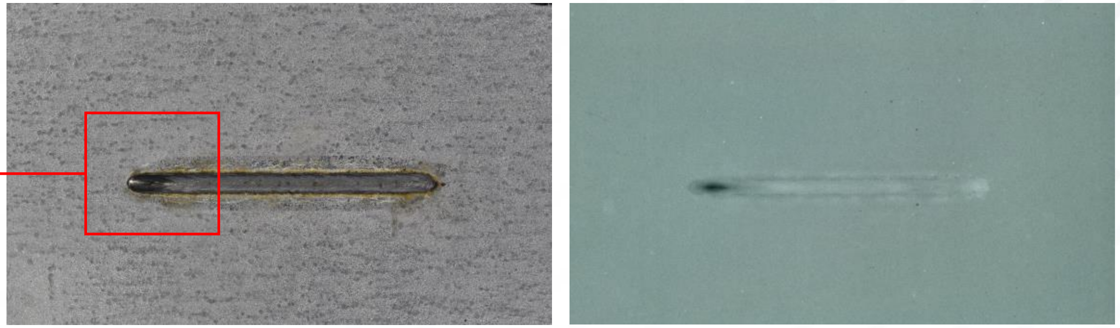
- Laser Beam Welding (LBW) is a known single-sided fusion welding process for sheet metal.
- LBW is commonly used in automotive for Body Structures (BSO, B-Plr, Bumper) and Closures (Liftgates, Tailgates)

BACKGROUND

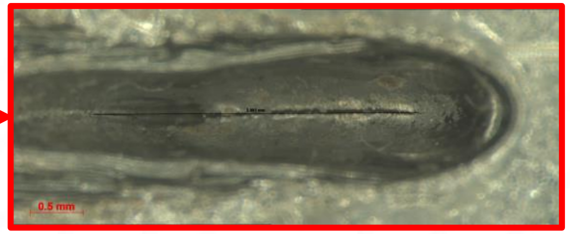
- AHSS usually exhibit crater cracking during LBW using SEP1220-3 standard. This phenomena has been also observed clearly in Zinc coated 3rd Gen AHSS which is the objective of this presentation.
- **What is a crater crack?** *A common crack that occurs during the weld pool solidification at the end of the weld metal.*
- **Why the cause?** *Fast cooling rates, weld bead size/shape, segregation of alloying elements.*
- **Why is important to avoid them?** *They can easily propagate through the weld bead under high restraint conditions or dynamic loading.*

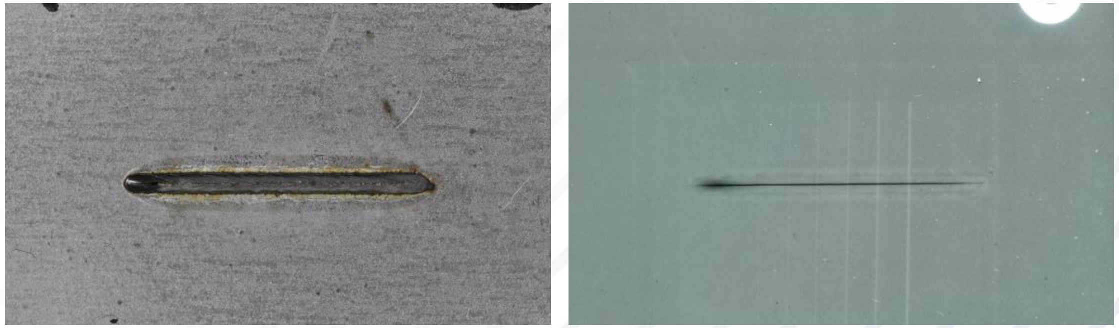
Images from SEP1220-3 Standard Test

Surface Inspection | X-ray Inspection



Crater crack example in Gen3 for 25mm Laser weld



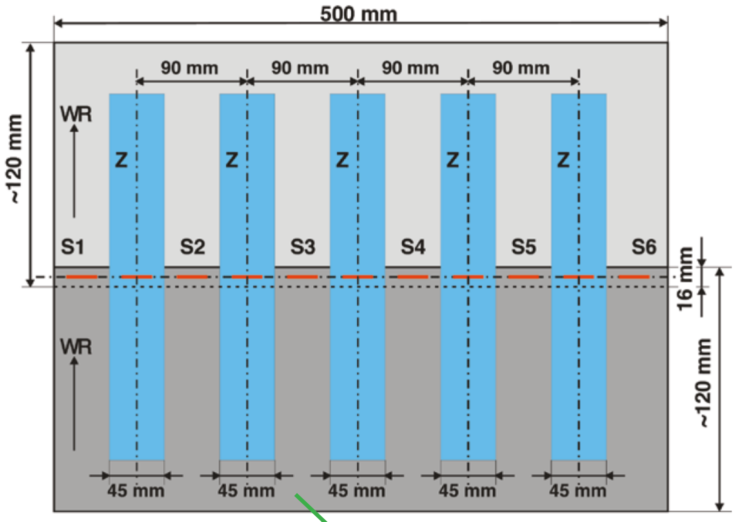


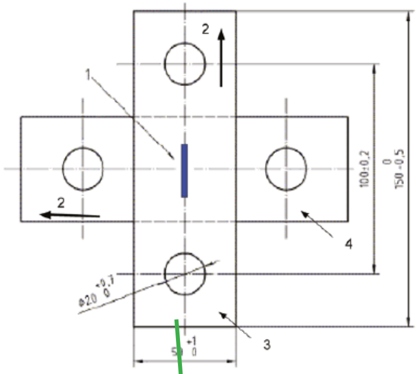
Longitudinal crack example in Gen3 for 25mm Laser weld

LBW DEVELOPMENT – EXPERIMENTAL SETUP

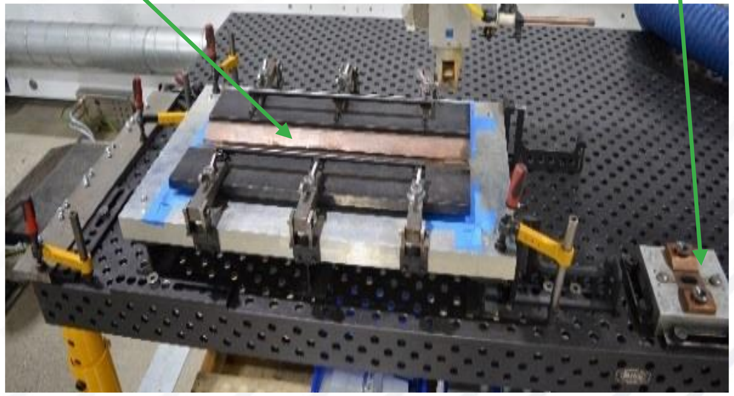
- Test Location: Fraunhofer
- Material: 1.6mm Fortiform® 980 GI
- Weld Protocol: ***Modified SEP-1220-3***
  - Joint : Overlap Through
  - Geometry: Stitch 25mm
  - Configuration: Tensile Shear & Cross Tension
  - Modified Power Ramp Down → “Crater Fill”*
- Inspection Method
  - Visual and Surface Inspection
  - Cross Sectioning
  - Electron Probe Microanalysis

Tensile Shear and Cross Tension Configuration for welding , *Source: SEP1220-3*





Weld Test Fixture, *Source: Fraunhofer*

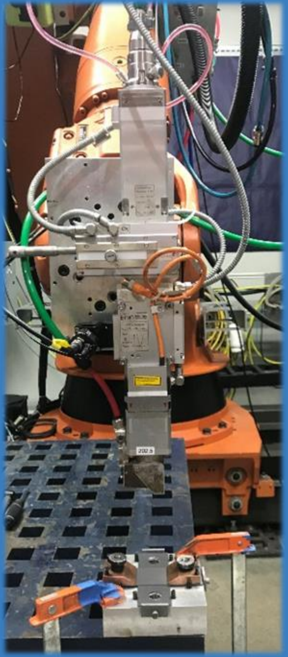


* Crater Fill: More Information refers to slide #7.

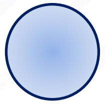
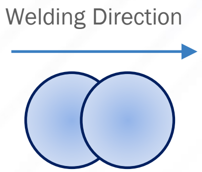
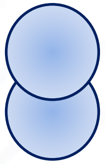
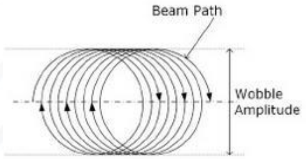
LBW DEVELOPMENT – LASER SETUP & TECHNOLOGIES

Laser Setup

- Laser : Trumpf Trudisk 6001 (Brightline)
- Laser Head: Highyag BIMO & IPG D30(Wobble)
- Robot : Kuka KR100
- Welding speed: ~3.0 m/min
- Power: 4.0 kW
- Focal Length: 200mm
- Fiber Diameter: 300 μm
- Focus Spot Size: 600 μm



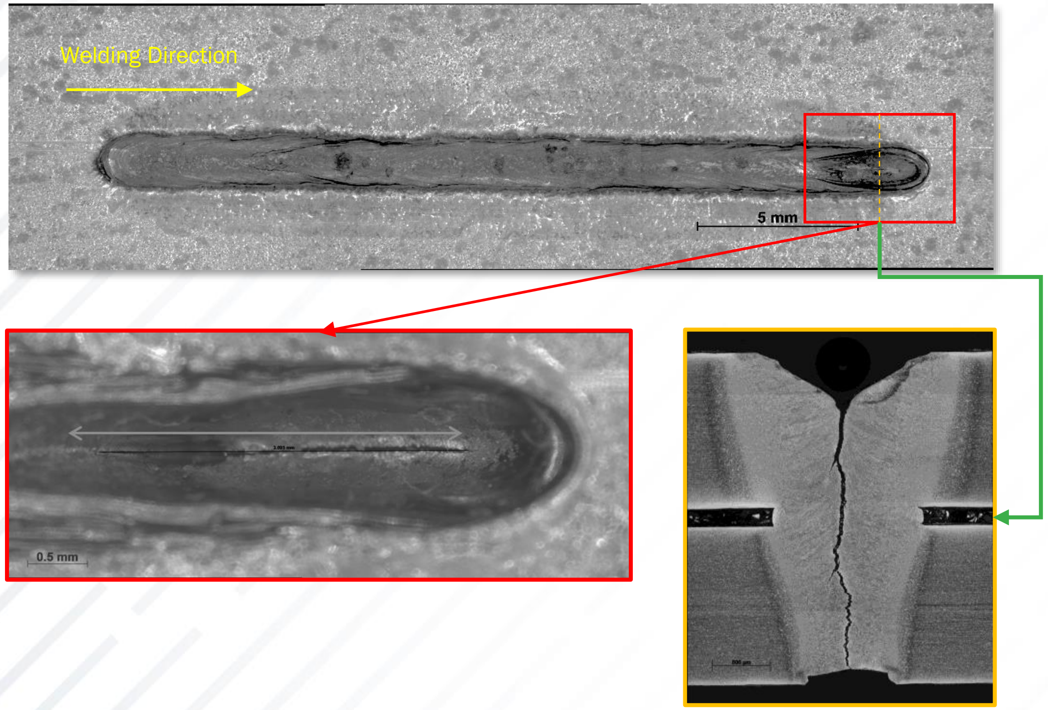
Technology Matrix

	Technology	Objective	Geometry
1	Single Spot SEP1220-3	Baseline	
2	Single Spot “Crater Fill”	Reduce crater cracking	
3	Twin Spot Trailing with Crater Fill	Extend the solidification rate by distributing power intensity to lead/trail spot	
4	Twin Spot Side by side with Crater Fill	Improve weld strength by a wider cross-sectional weld metal	
5	Wobble with Crater Fill	Stabilize weld pool solidification	

All Modified Technologies examined here showed some reduction of crater crack (Slide#9), however, most of microstructural and post-weld mechanical characterization were studied for Single Spot “Crater Fill” technology.

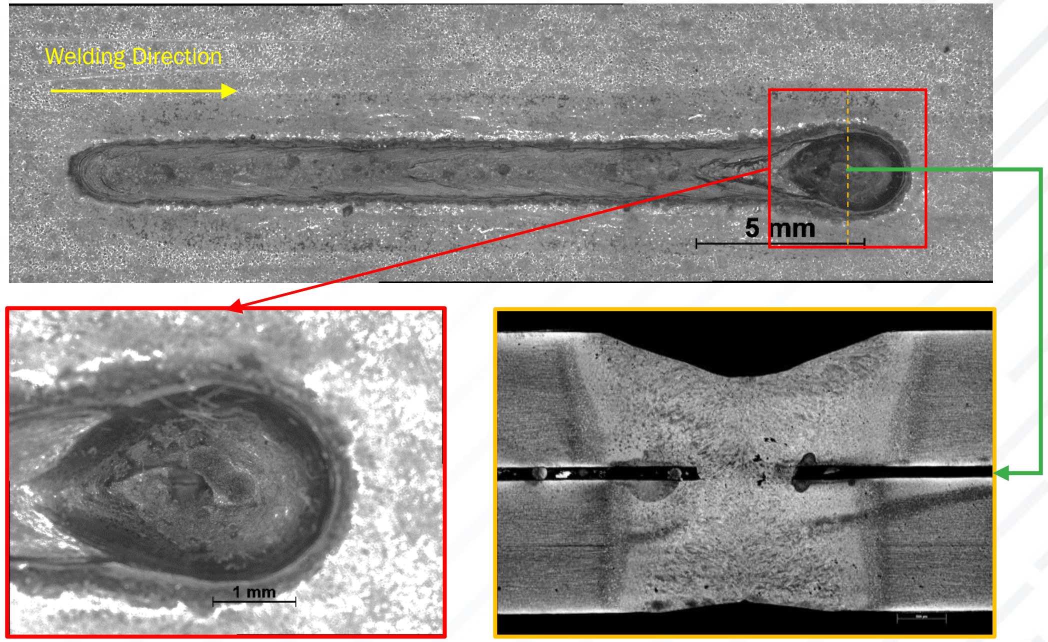
CRATER CRACK OPTIMIZATION-SURFACE CHARACTERIZATION

#1- Single Spot Standard SEP 1220-3



The existing power ramp down mandated by SEP1220-3 trigger severe crater cracking.

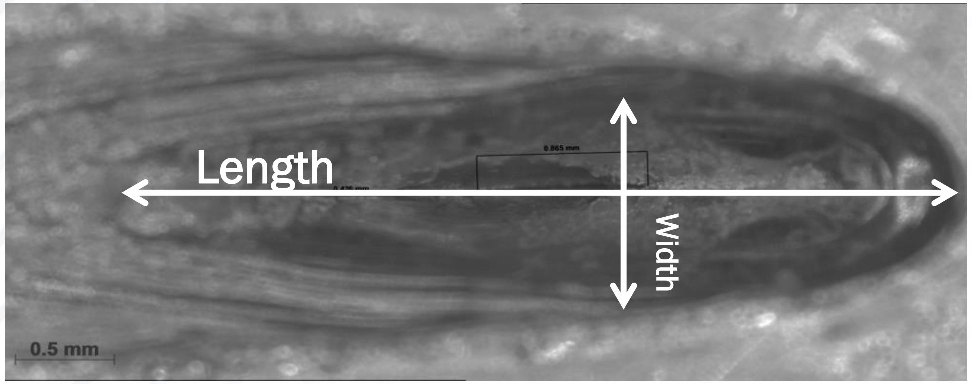
#2- Single Spot “Crater Fill”



The crater fill technique involves a power step down with prolonging cooling time to drastically reduce the crater cracking and mitigate potential delayed cracking under restraint conditions.

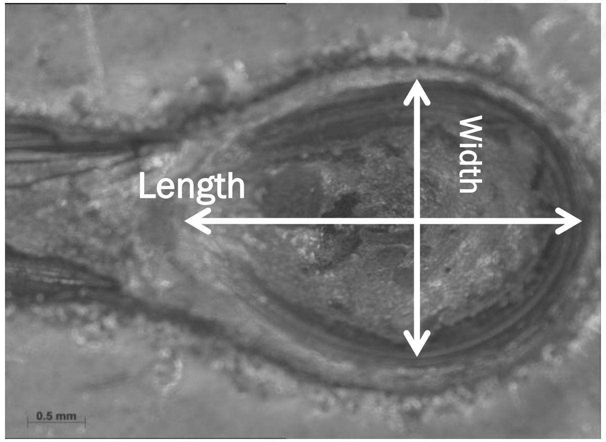
CRATER CRACK OPTIMIZATION- ASPECT RATIO

#1- Single Spot Standard SEP 1220-3



Length- Top	Width- Top	Length-Bottom	Width- Bottom
4	*1.25*	*3.8*	*0.9*
Aspect Ratio: 3.2		*Aspect Ratio: 4.25*	

#2- Single Spot "Crater Fill"

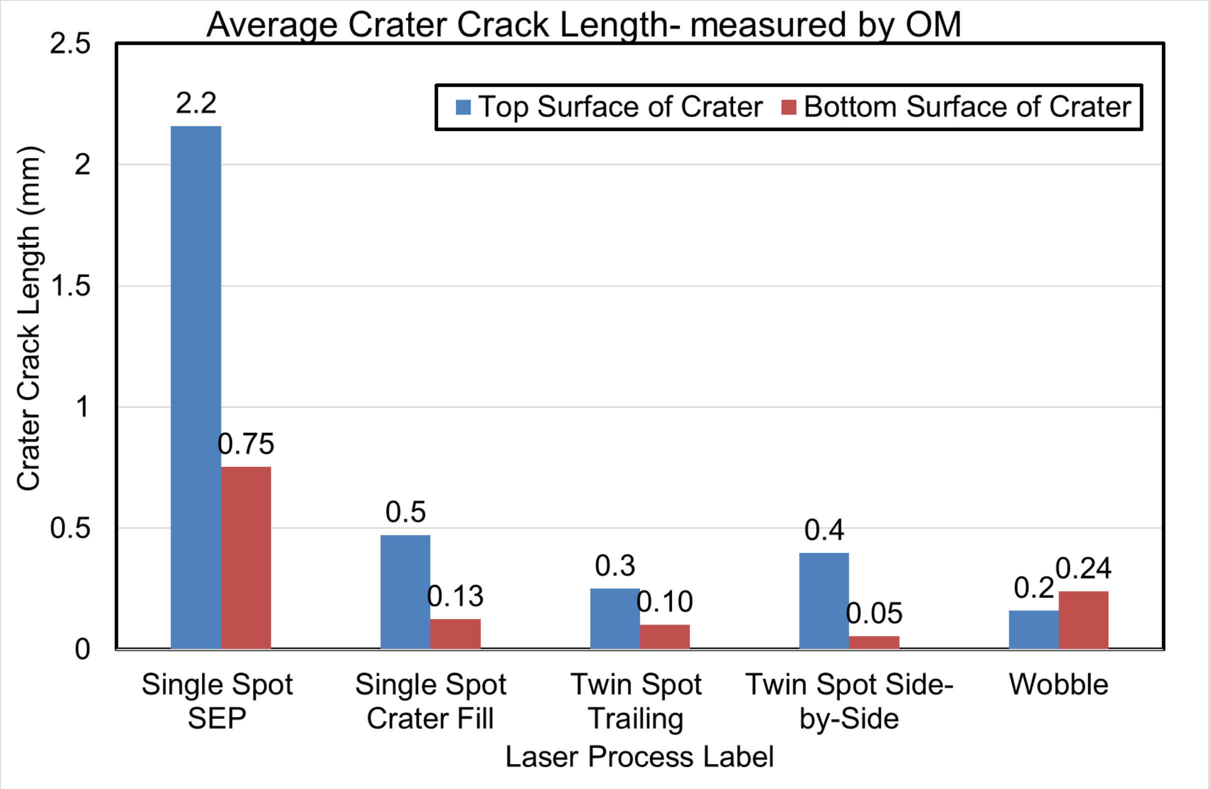


Length- Top	Width- Top	Length-Bottom	Width- Bottom
3.2	*5.3*	*2.8*	*1.9*
Aspect Ratio: 0.6		*Aspect Ratio: 1.5*	

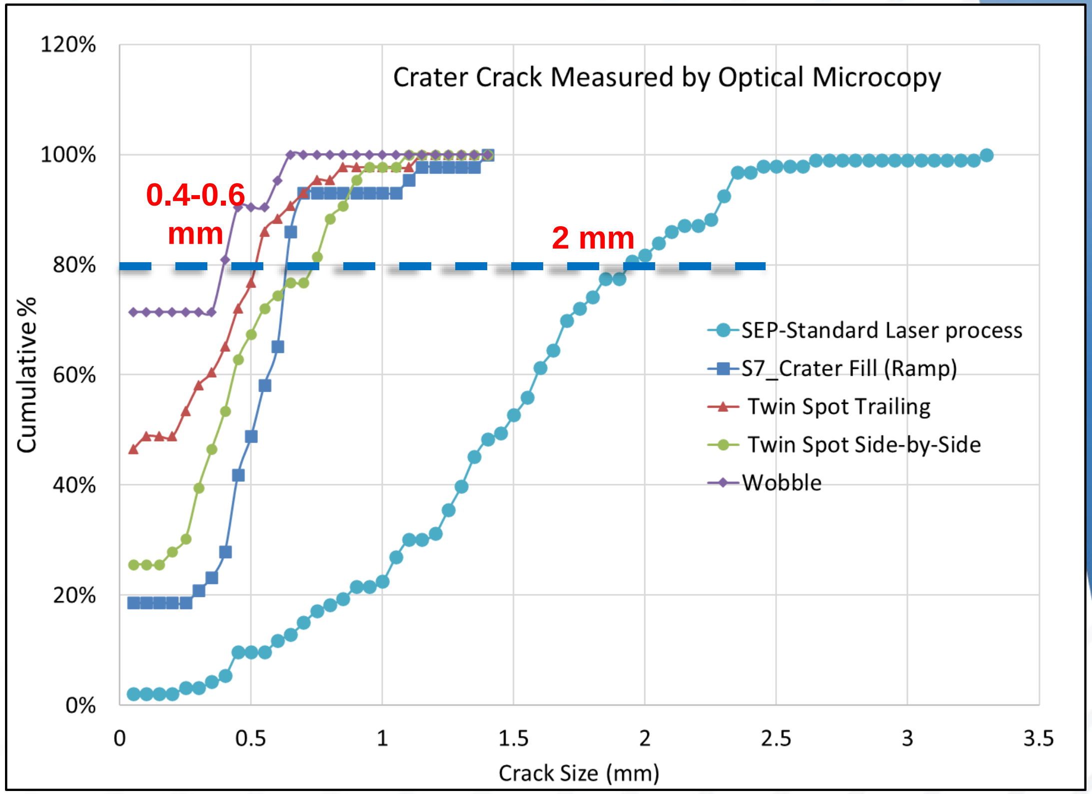
- An elongated crater shape in 3rd Gen AHSS demonstrated poor resistance to centerline cracking.
- After modification, Aspect Ratio (Length/ Width) is reduced significantly.
- Aspect Ratio is an evident surface measurable between end crater geometry and it is more pronounced for top surface of craters (~5 times) as compared to bottom surface of crater (~ 2.8)

STATISTICAL ANALYSIS OF IMPROVEMENT

Crater Crack Length per Laser Technology



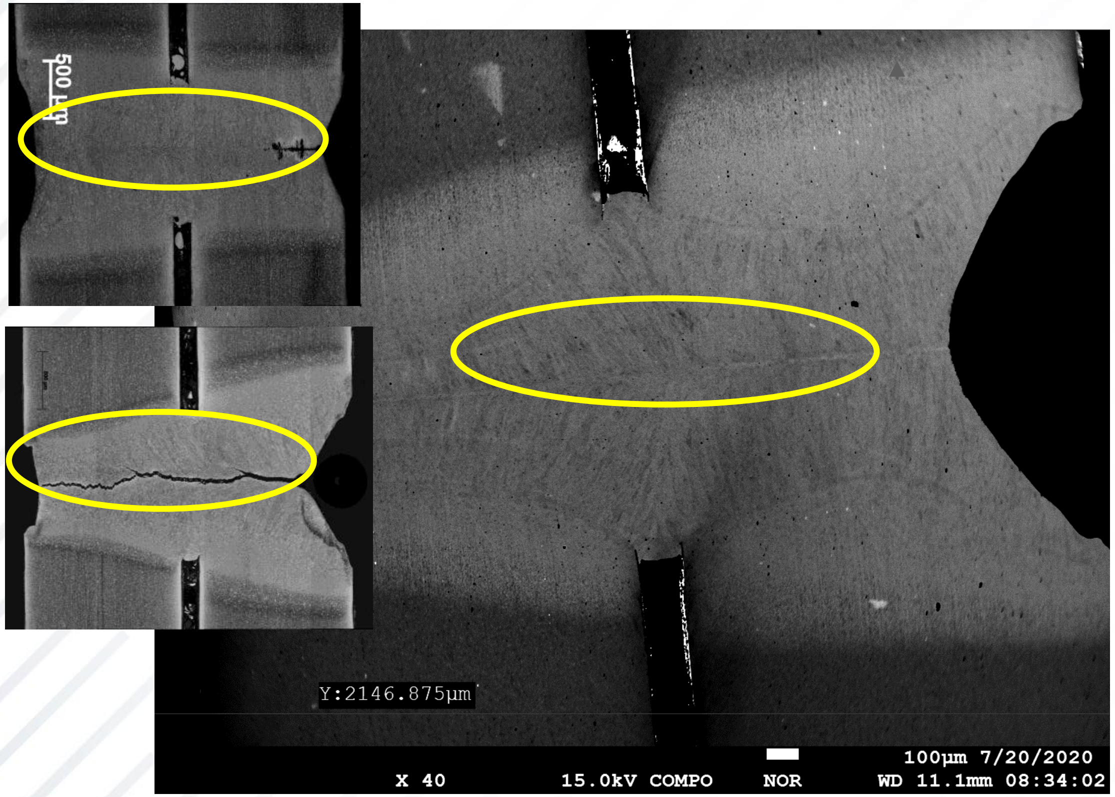
Cumulative % per Crater Crack Length



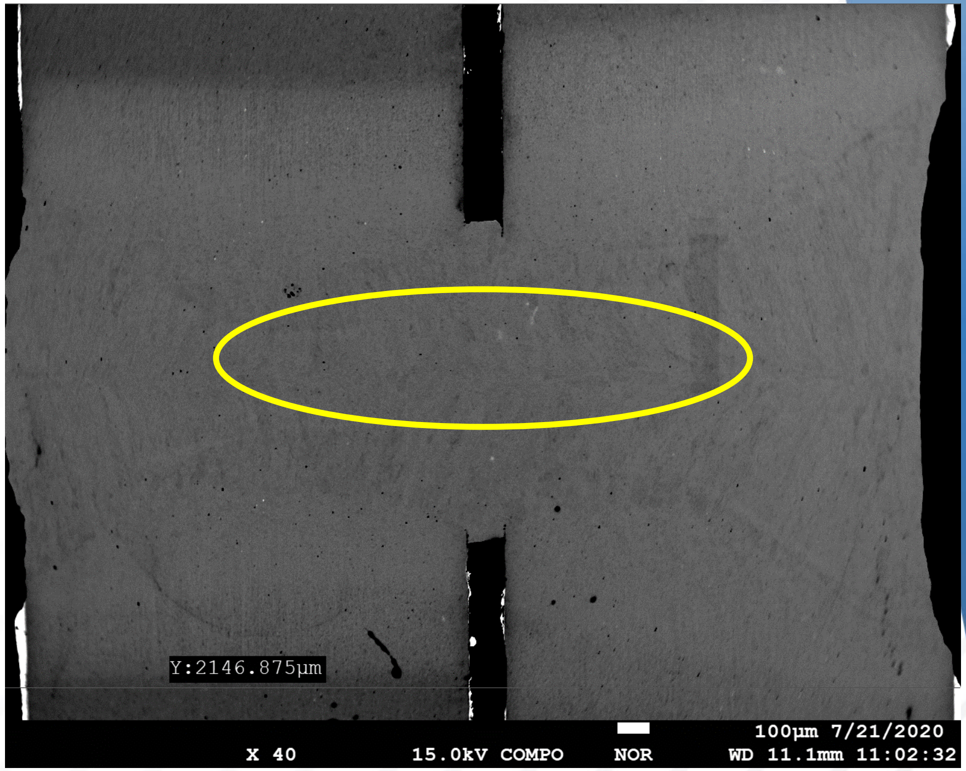
- Significant reduction in crater crack size from SEP standard to other modified laser processes developed in this study.
- From Cumulative percentages of cracks, between SEP standard and 4 different modified laser process:
  - 80% percent of samples in SEP standard have crater cracks up to 2 mm
  - However, 4 types of modified process show crater cracks below 0.4 - 0.6 mm for 80% of tested samples.

UNDERSTANDING THE WELD MICROSTRUCTURE

#1- Single Spot Standard SEP 1220-3



#2- Single Spot "Crater Fill"



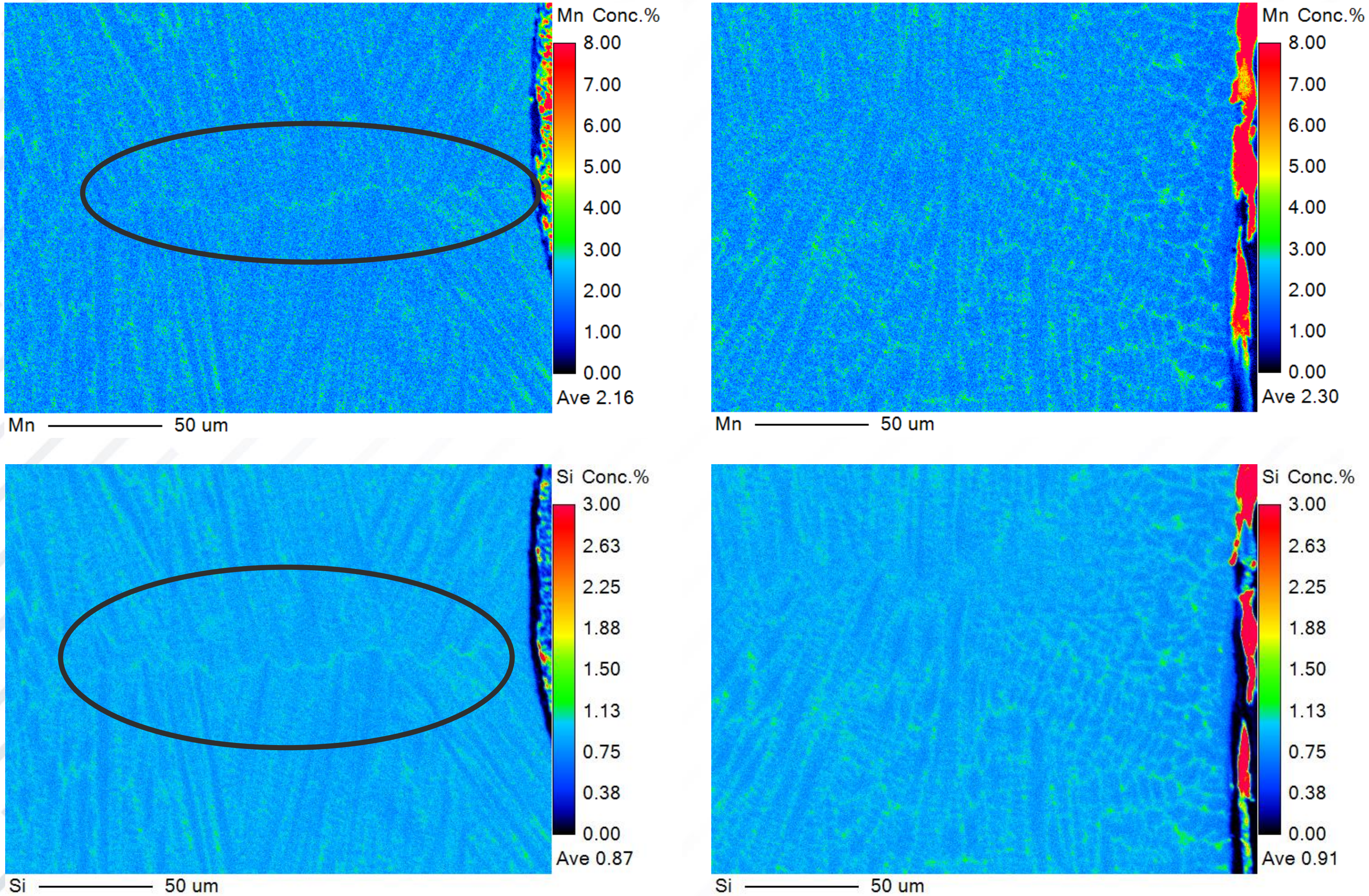
Cross Section Analysis of welds at crater

- High tensile strain concentrated at the central solidification line for elongated crater end-shape.
- Crater Fill shows equiaxial grain formation preventing of crater crack formation.

UNDERSTANDING THE WELD MICROSTRUCTURE

#1- Single Spot Standard SEP 1220-3

#2- Single Spot "Crater Fill"



Electron Probe Micro Analyzer (EPMA) of weld at crater

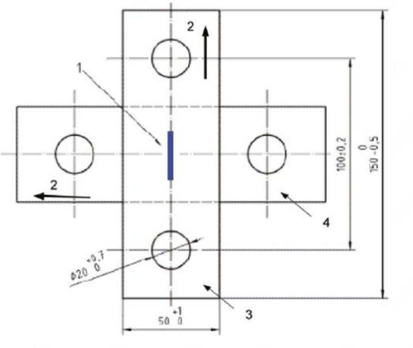
Alloying Element Segregation in Central Solidification Line

- Segregation of Mn and Si in central solidification line is noticeable for SEP standard:
  - Weakness area for formation of liquation crack (hot cracking) due to delay in solidification during cooling and high tensile stress from neighbor solidified area.
- This scenario is disappeared for modified laser process and no segregation of Mn and Si in solidified center line.

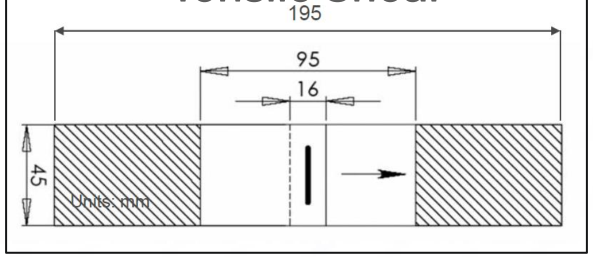
WELD STRENGTH TEST SETUP

Coupon Geometries

Cross Tension



Tensile Shear

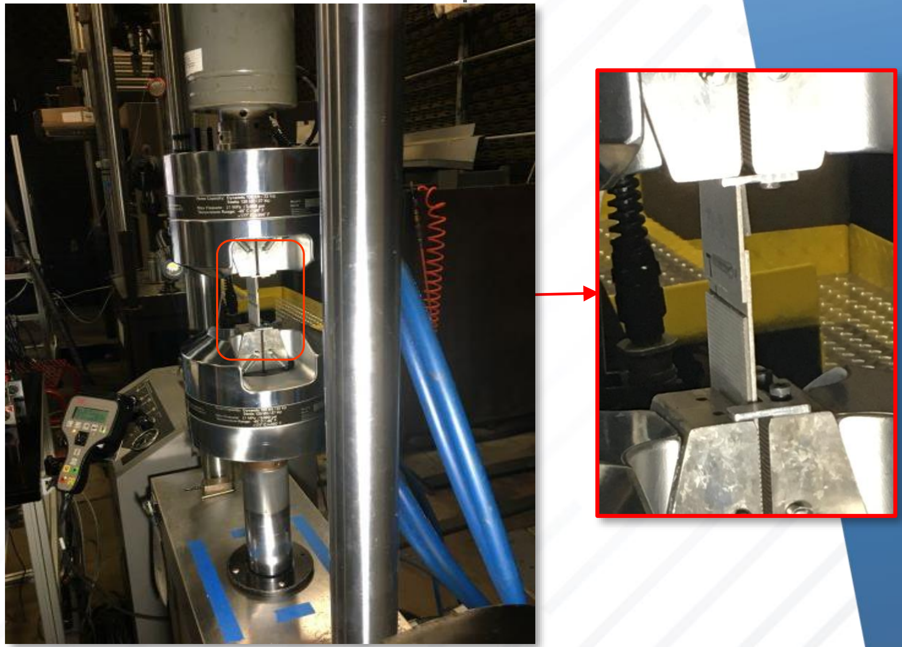


Quasi-static Test Condition: Displacement Rate Control: 10mm/Min.

Fatigue Test Conditions:

Test	Equipment	Fatigue Testing parameters
Tensile Shear	• Machine: MTS fatigue tester • Load cell: 20,000 lbs • Displacement (LVDT): ±6 inch	• Load ratio R=0.1. • Load control (HCF) with frequency of 10Hz. • Maximum load: 3000 N, 4500 N and 9000 N. • Run-out cycles: 10 million
Cross Tension		• Load ratio R= -1. • Load control (HCF) with frequency of 10 Hz. • Load amplitude: 500 N, 1000 N and 2000 N. • Run-out cycles: 10 million.

Tensile Shear Setup

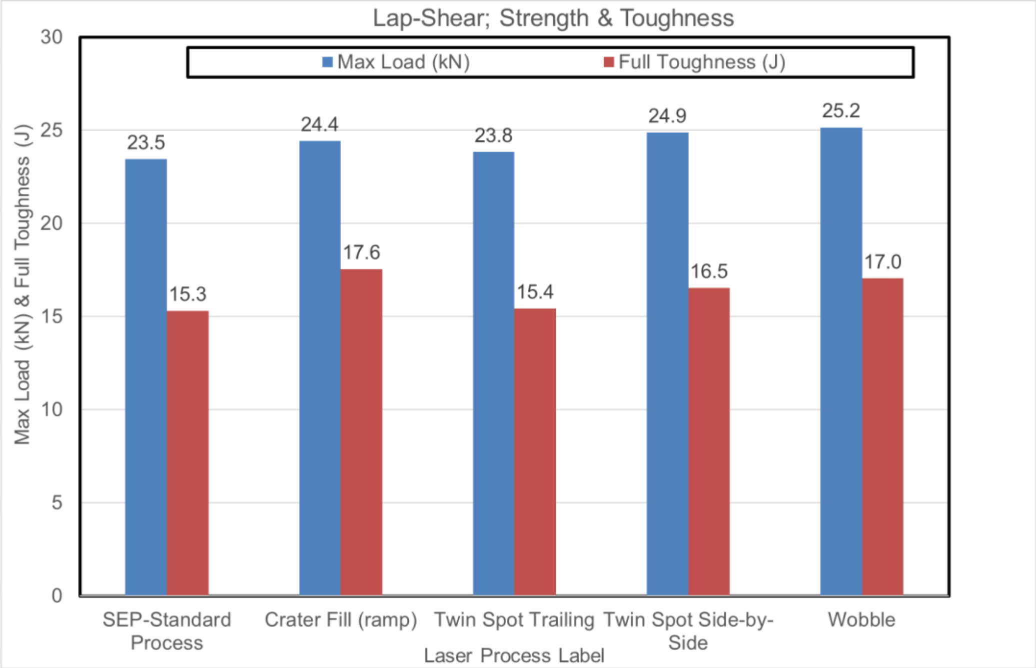


- Testing was performed per Ford protocol.
- Two analytical models, Stromeyer model and Basquin model, were used to predict the fatigue limit.

QUASI-STATIC STRENGTH

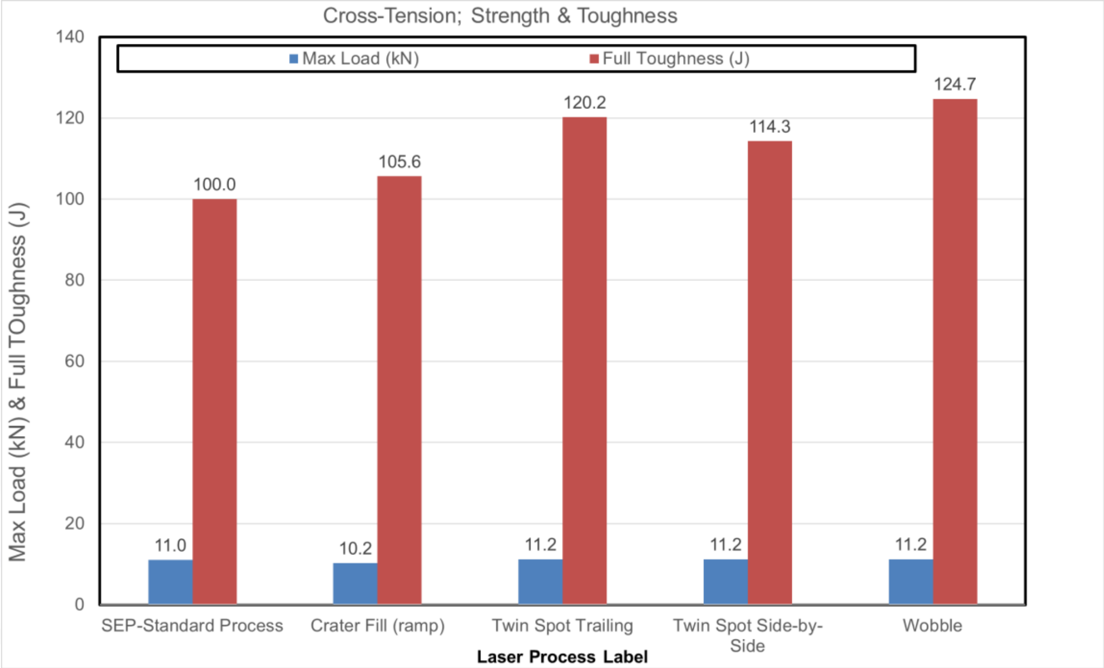
Tensile-Shear Strength

Max. Load and Full toughness (area under of full F-D curve)



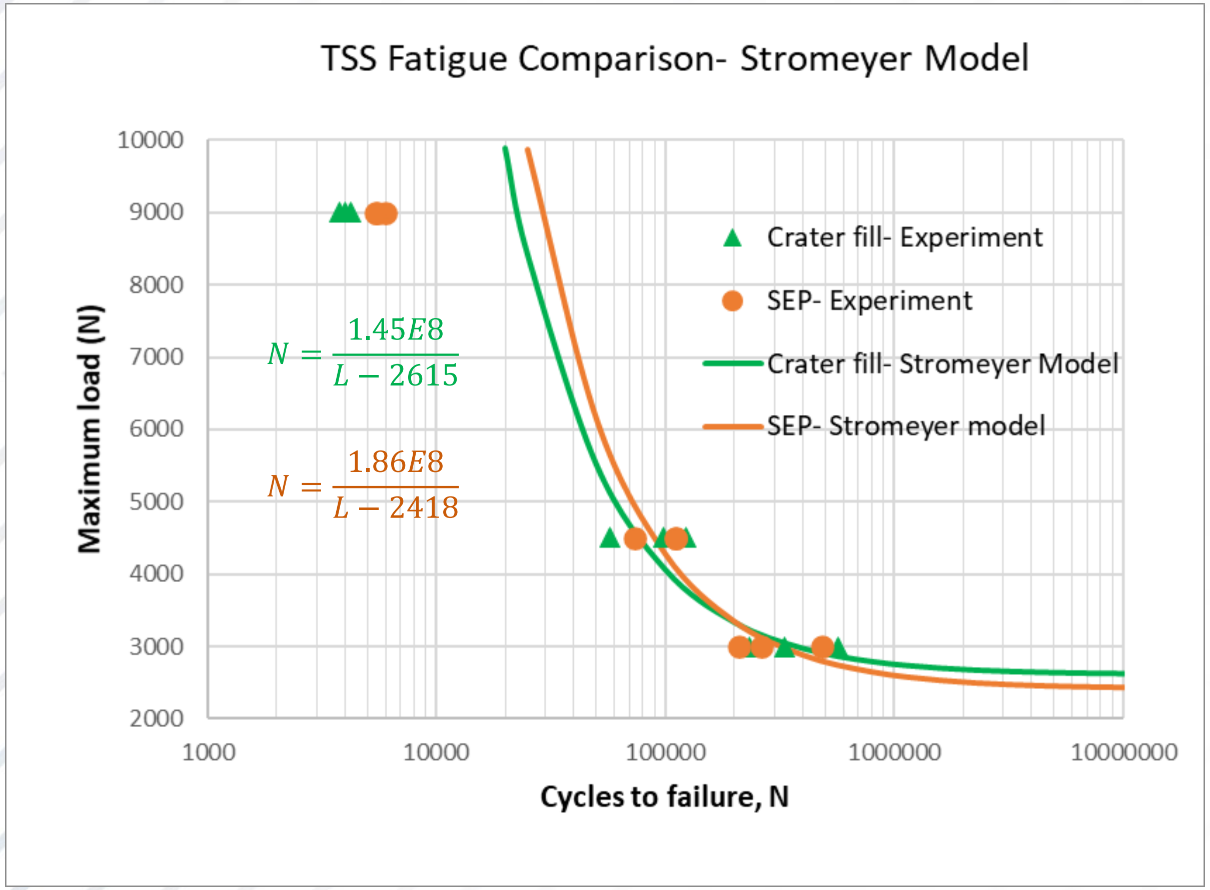
Cross-Tension Strength

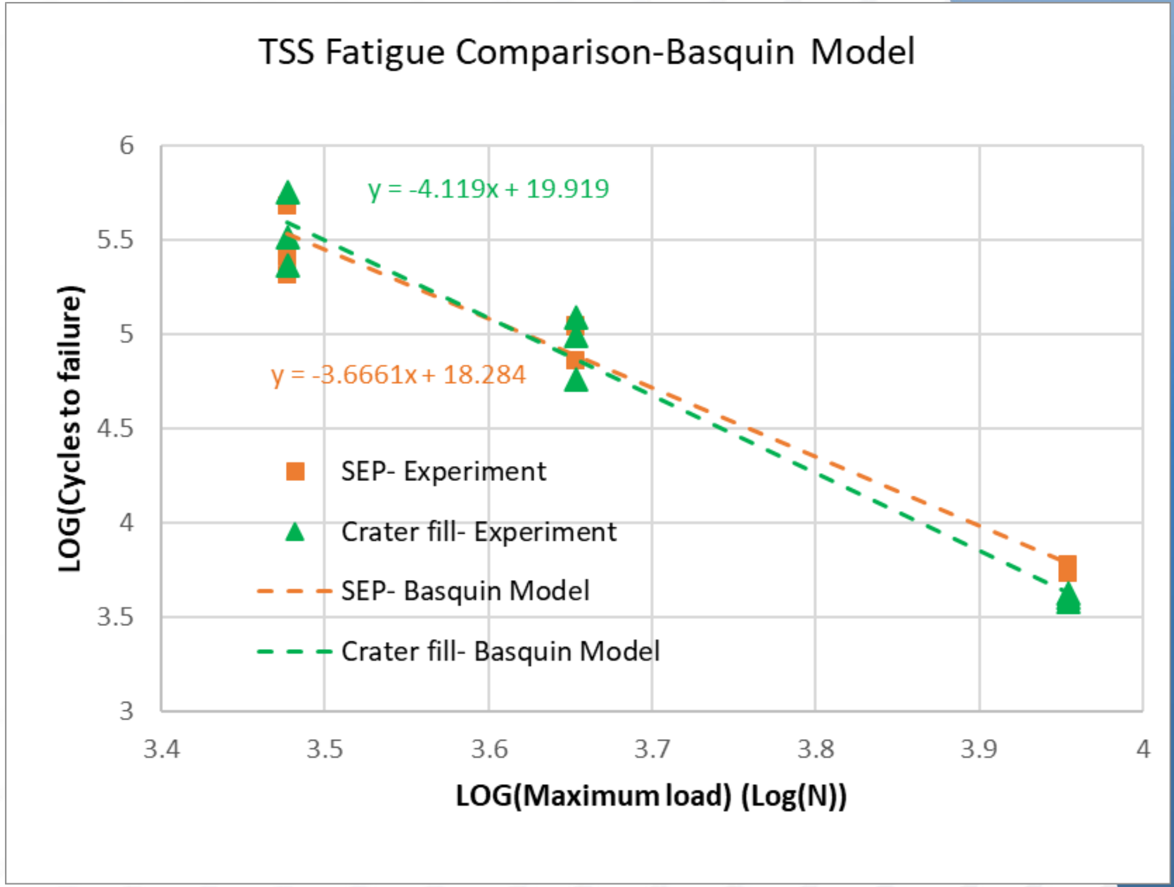
Max. Load and Full toughness(area under of full F-D curve)



- Quasi-static strength (cross-tension and tension-shear strength) is not affected significantly by crater crack, even though crater cracks are reduced significantly from SEP standard to new modified laser process
- Crater crack size seems not that long, even in SEP standard, to affect quasi-static mechanical properties. How about Fatigue?

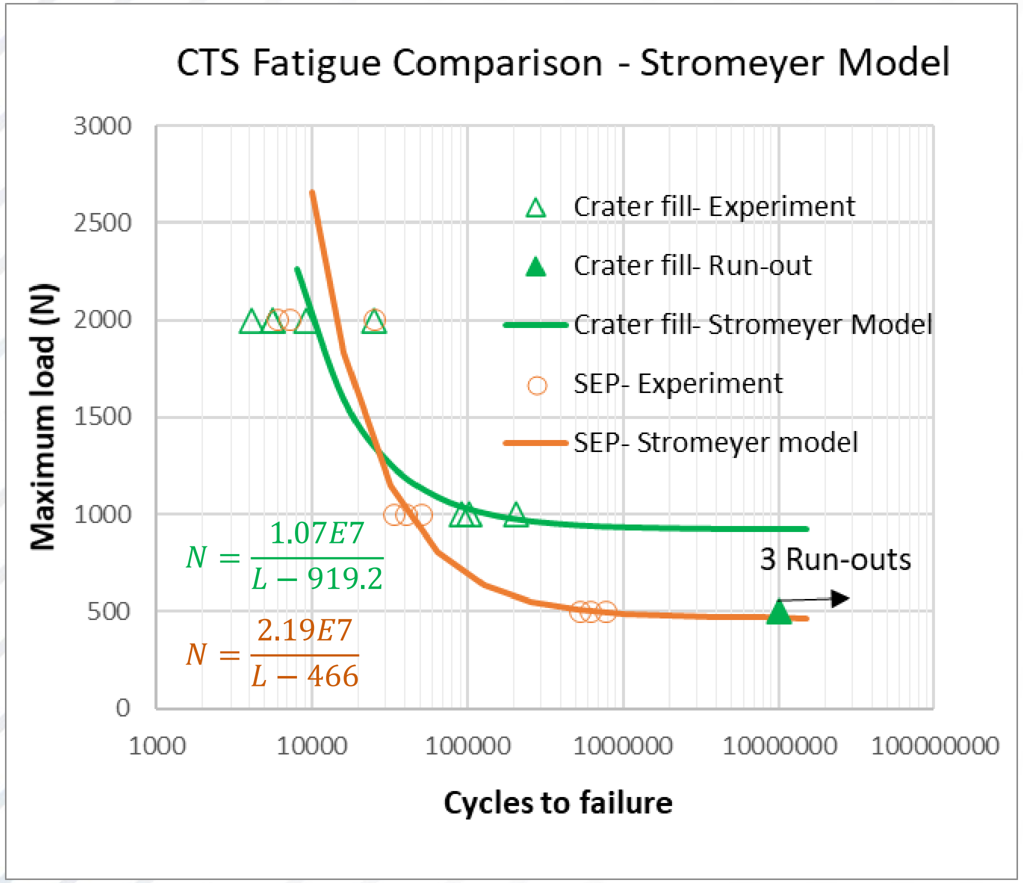
FATIGUE: TENSION-SHEAR

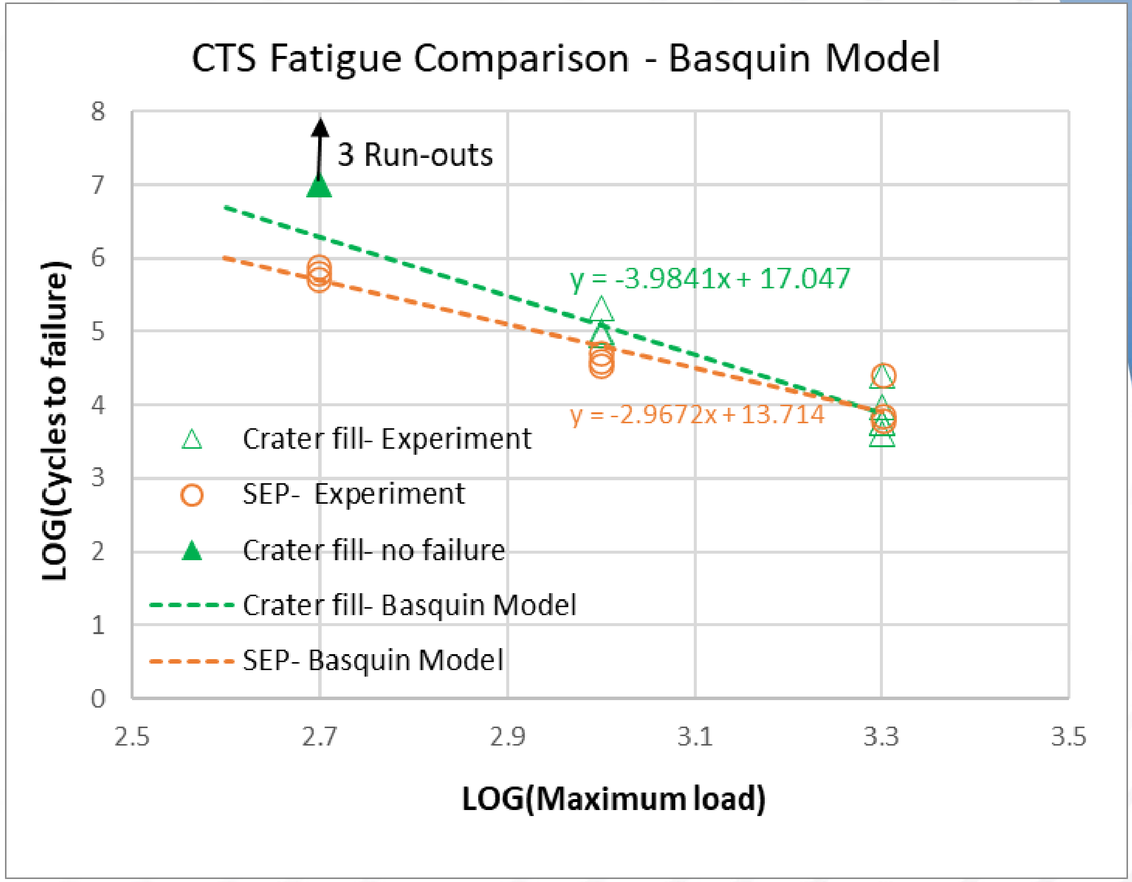




The result of TSS fatigue test showed that fatigue limit of Crater Fill welds was slightly higher than SEP standard welds.

FATIGUE: CROSS-TENSION





- The result of CTS fatigue test showed clearly that fatigue performance of Crater Fill was better than SEP standard weld.
- Fatigue limit for Crater fill is around twice higher than SEP Standard weld.

CONCLUSIONS

- In this study the crater crack in Zn Coated 3rd Gen AHSS was studied, and laser process modifications were investigated to overcome the cracking mechanism.
- All four technologies described here significantly reduced crater cracking in 3rd Gen AHSS.
- Among the four examined technologies, Single Spot Crater Fill is the preferred method, since it only requires programming refinement with existing laser systems.
- The Aspect Ratio (Length/Width) validates that a rounded crater shape leads to a higher cracking resistance. No delayed cracking was observed after parameter optimization.
- EPMA clearly shows the advantages of these enhancements by changing the solidification mechanism that suppresses the alloying elements segregation between dendrites.
- Quasi-static strength (cross-tension and tension-shear strength) is not affected significantly by crater cracks within a weld.
- Fatigue tests demonstrate that crater cracks affect the weld performance in cross tension loads, and this is significantly improved with the Single Spot Crater Fill Technology.

THANK YOU!...FOR MORE INFORMATION

GDIS

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