

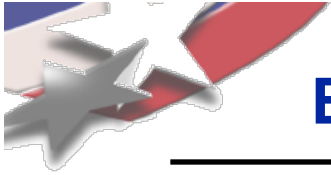


Effects of Surface Chemistry on Asymmetry in Stainless Steel Welds

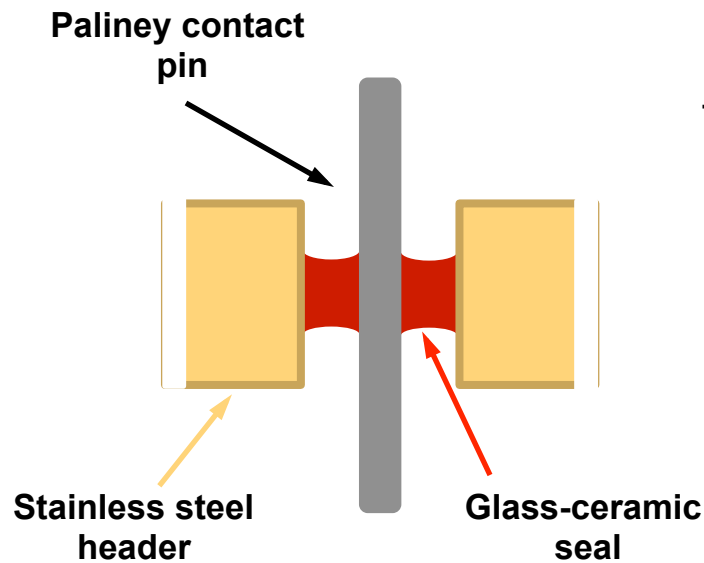
C.V. Robino, D. F. Susan, S. M. DeBlassie,

Presented by G. A. Knorovsky

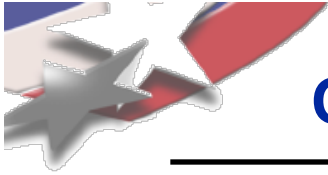
Sandia National Laboratories
Albuquerque, NM 87185



Background and issues

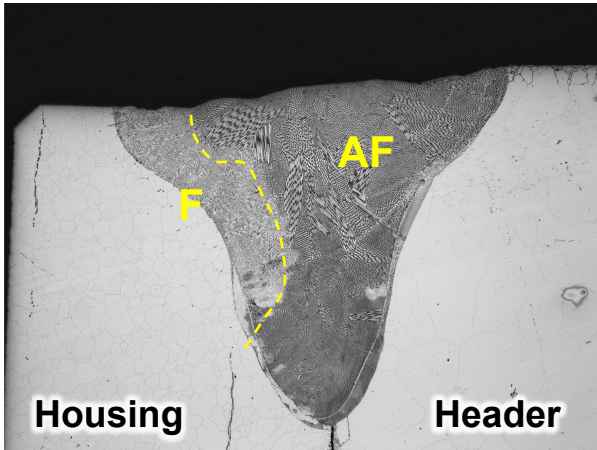


- Implementation of new Glass-Ceramic (GC) sealing technology in electrical headers resulted in visible discoloration (contamination) of the weld joint and asymmetric weld cross-sections
- Of potential concern are the effects of these on:
 - Weld process repeatability and robustness
 - Solidification mode and weld cracking
 - Porosity
 - Weld properties
 - Weld inspection and acceptance
- We have attempted to assess and quantify these effects by evaluation of the chemical, geometric, and microstructural features of the welds

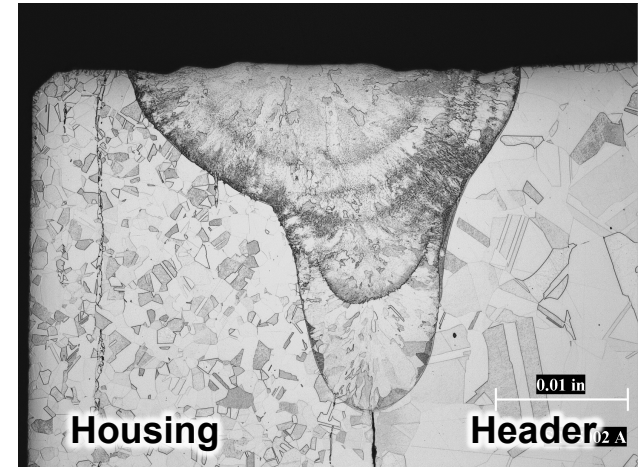


Qualitative observations

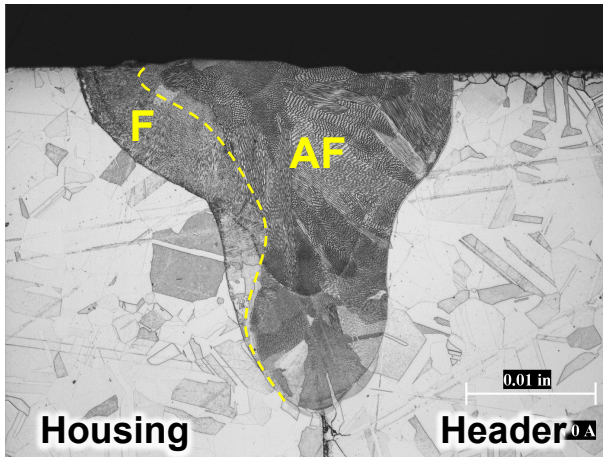
V1 GC Header



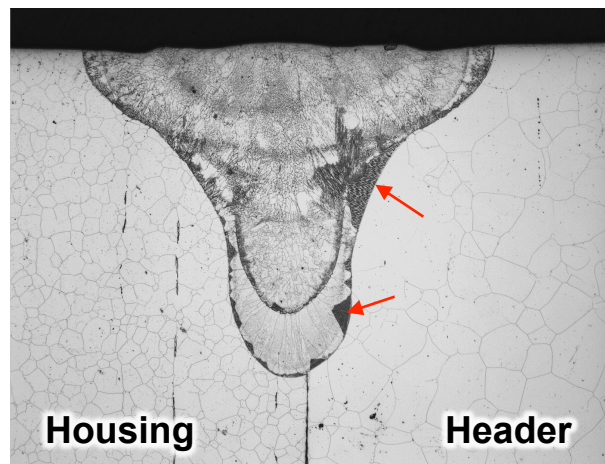
V2 Header / V1 Process



V2 Header, V2 Process

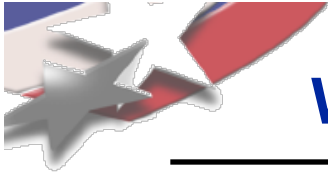


Blank

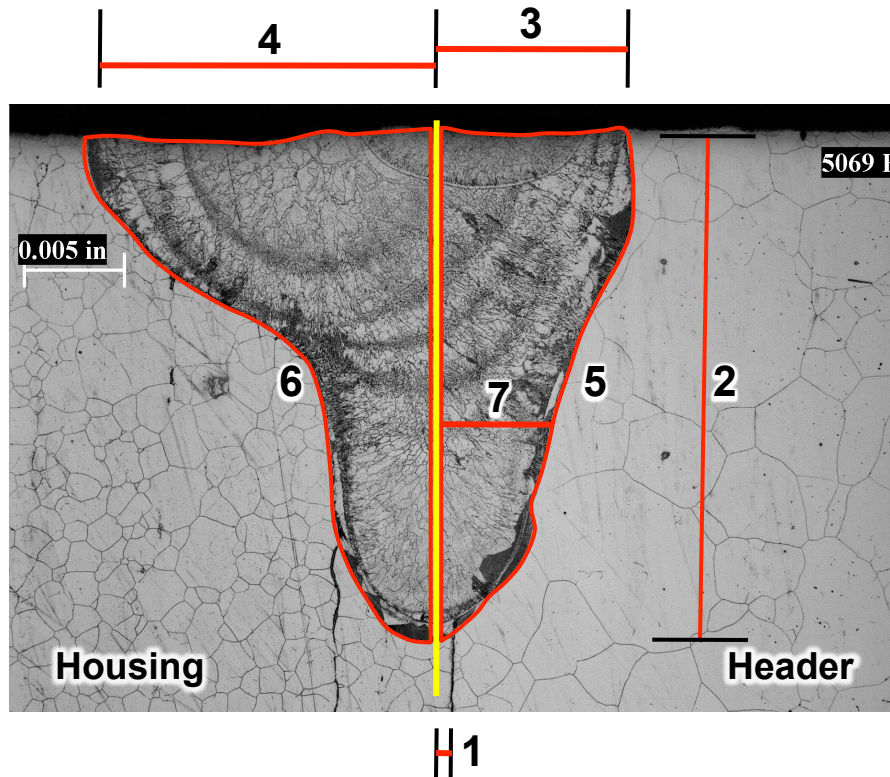


V2/V1 (chemically cleaned)





Weld feature measurements



1. Tracking Offset
2. Penetration
3. Surface Width (header side)
4. Surface Width (housing side)
5. Weld Area (header side)
6. Weld Area (housing side)
7. Half Width at 0.015"

In addition, each section was examined for evidence of cracking, porosity, and solidification mode

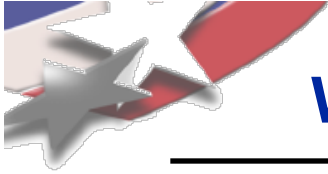
Populations Examined

Historical Type 1: Weld qualification and recent production lots, (8 welds – 30 sections)

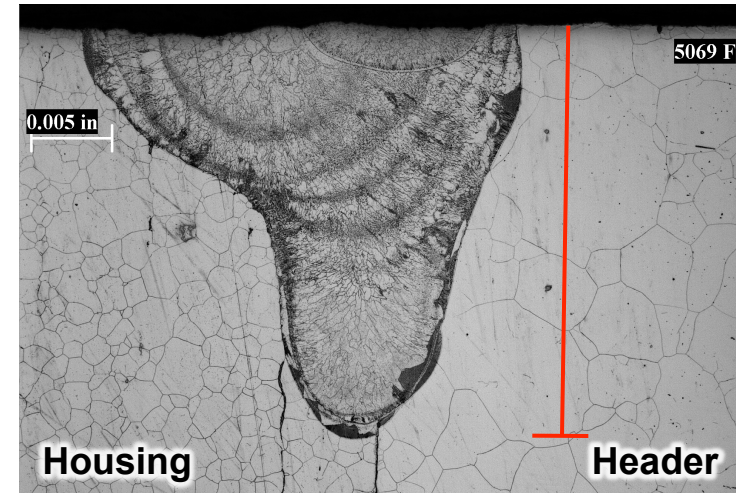
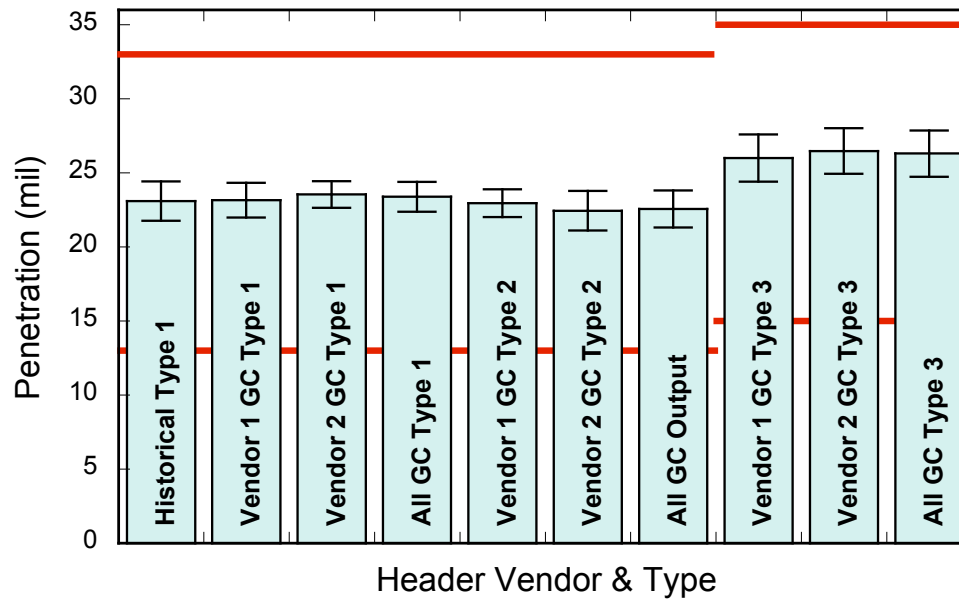
GC Type 1: 3 V2 + 2 V1 (5 welds – 20 sections)

GC Type 2: 6 V2 + 2 V1 (8 welds – 32 sections)

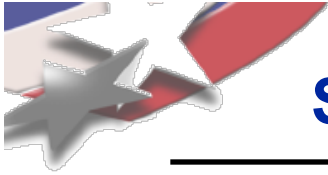
GC Type 3: 5 V2 + 3 V1 (8 welds – 44 sections)



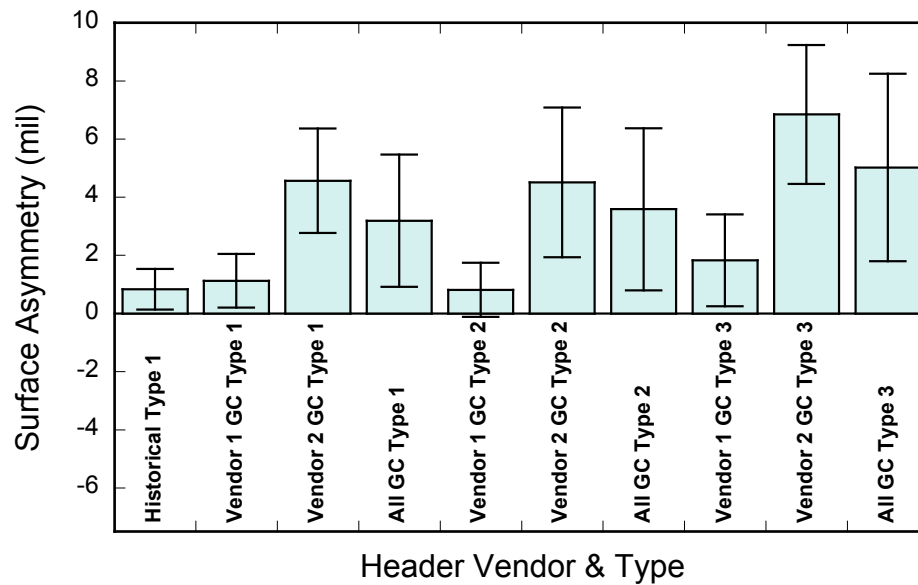
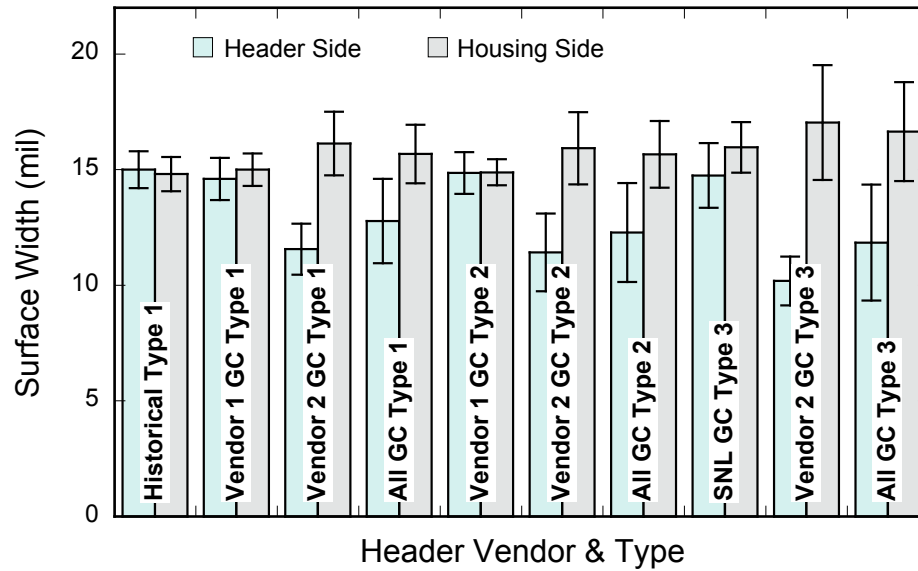
Weld Penetration



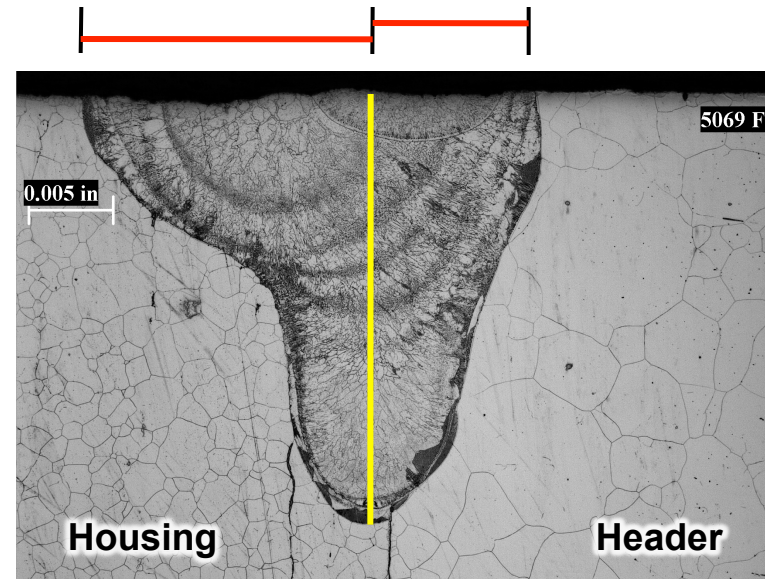
- Weld penetration appears to be unaffected, and is well centered within requirements
- There appears to be no significant change in variability (data is consistent with original statistical and qualification assessments)
- Cracking was not observed in any section
- Porosity was only observed in one section, and was well within size requirements
- Welds meet specification requirements with the possible exception of centering (to be discussed later)

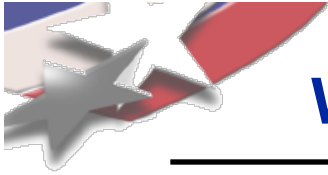


Surface widths and asymmetry

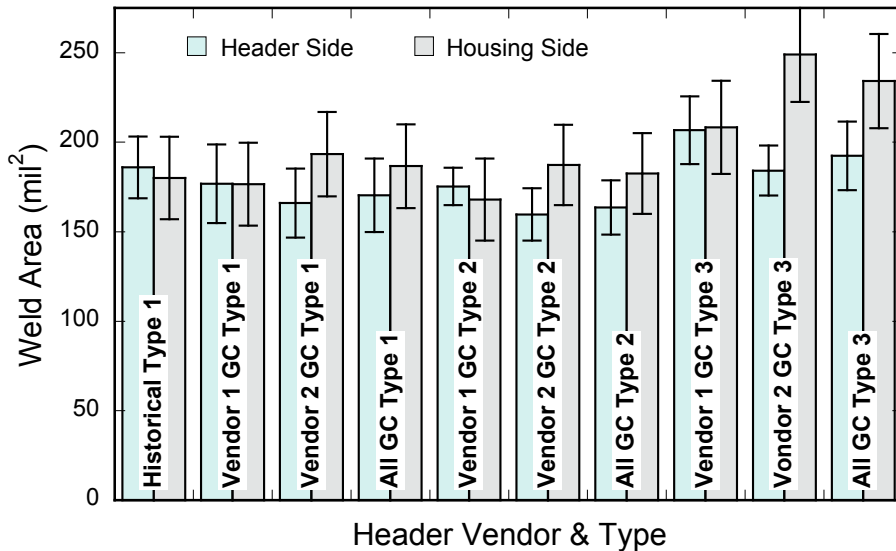


- Weld header and housing side widths are consistently imbalanced in Vendor 2 headers
- Imbalance favors housing side
- This requires significant changes to interpretation of visual inspection criteria

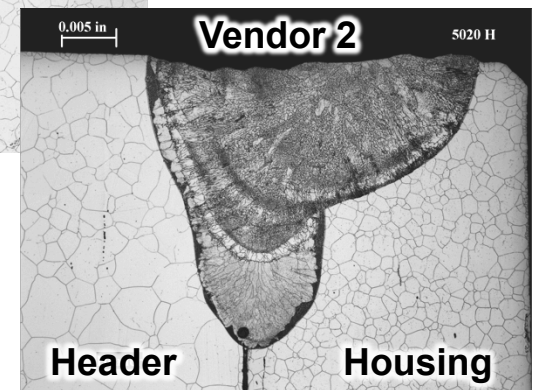
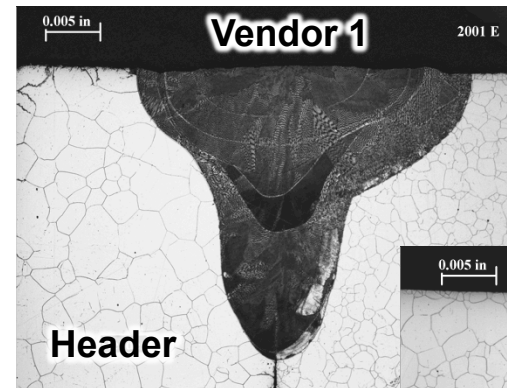
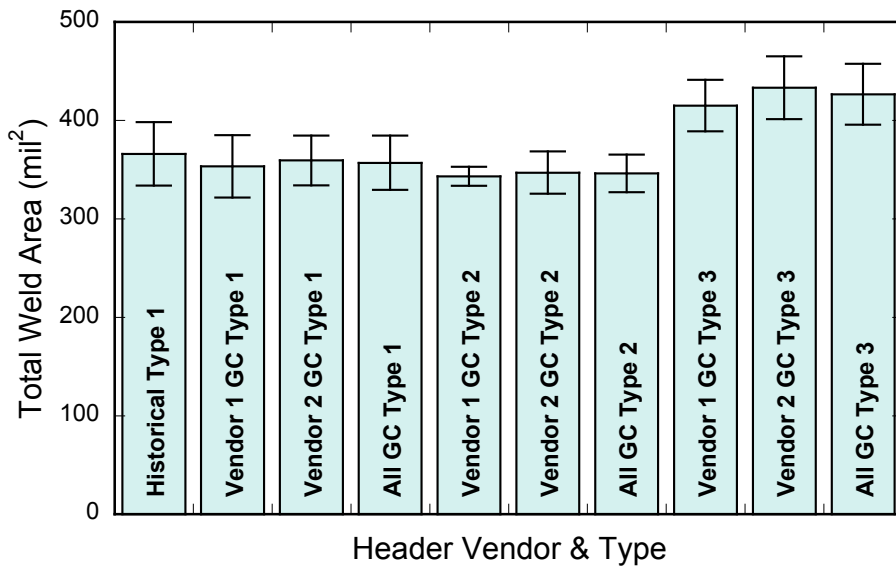


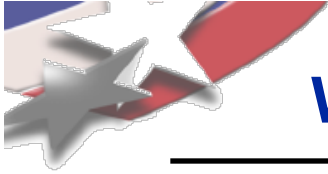


Weld area

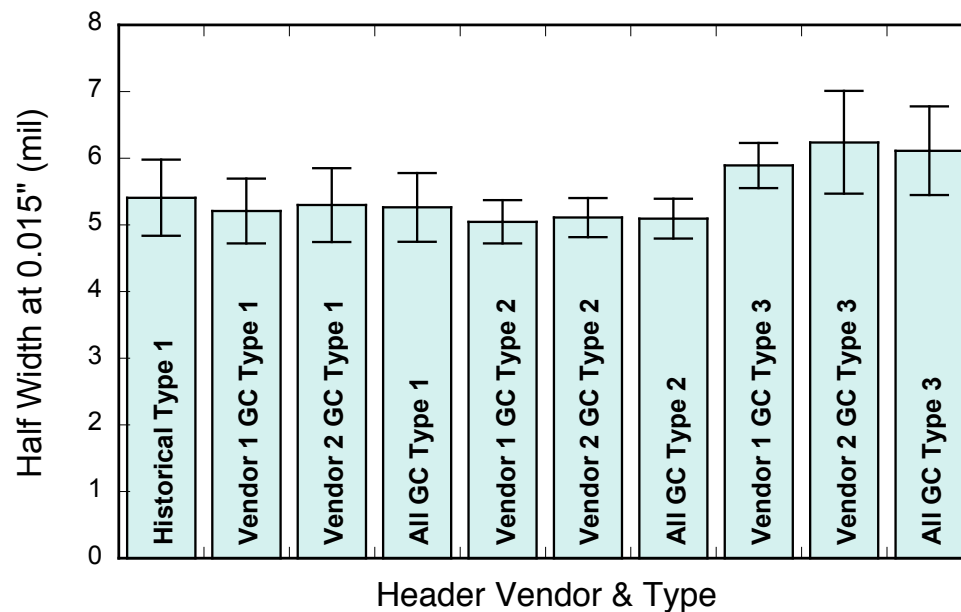
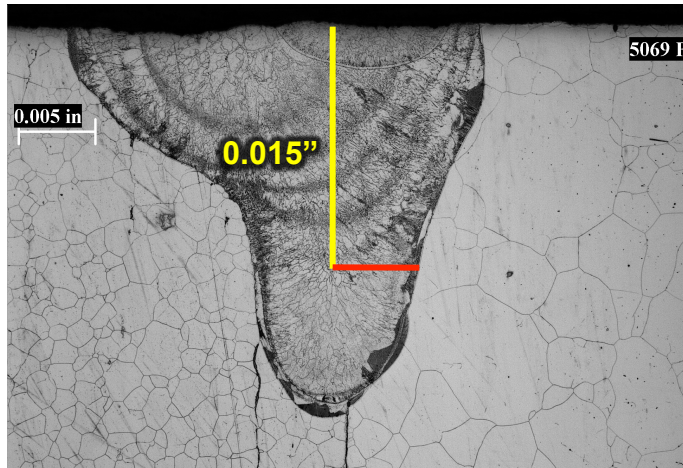


- Weld header and housing side areas are consistently imbalanced in Vendor 2 headers, less so in Vendor 1 headers
- Area imbalance favors housing side
- Total weld area (volume) appears to be unaffected and indicates no changes in weld energy transfer or melting efficiencies

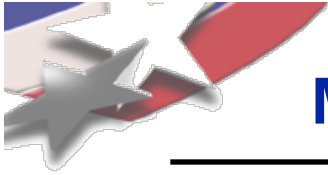




Weld half width at 0.015" depth

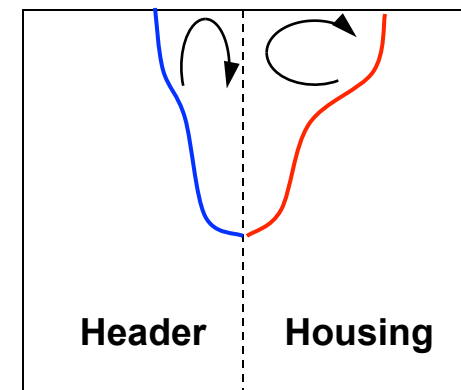
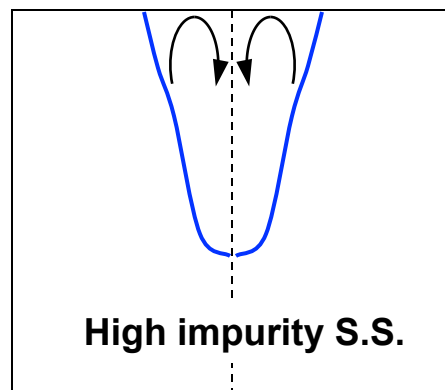
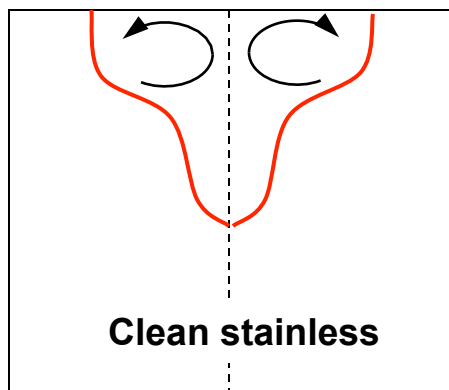
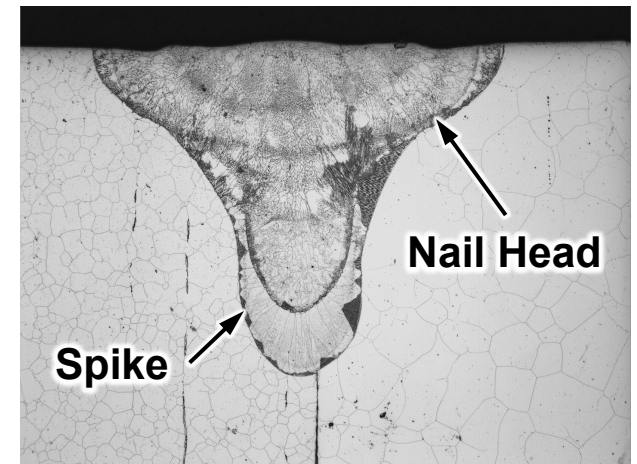


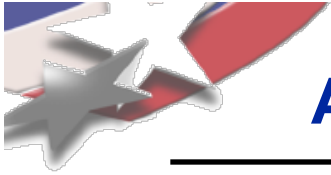
- Width appears to be essentially insensitive to impurities
- Weld width at this depth provides a measure of the sensitivity of the process to tracking error
- Implies process margins have not changed
- Note that, ideally, the Type 1 and Type 2 welds should have been assessed at 0.013" depth (the penetration minimum), but the 0.015" is representative (and conservative)
- Weld centering requirement can be addressed by specifying centering of the spike, but this does not address visual inspection requirements



Mechanism and implications for asymmetry

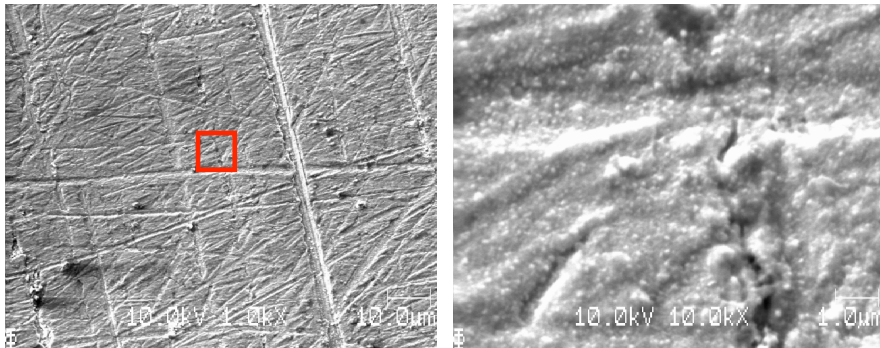
- Laser beam asymmetry and imbalanced heat sinking were evaluated and deemed not credible
- We believe the imbalance results from incomplete mixing (typical of laser welds) coupled with surface tension driven fluid flow (Marangoni convection)
- This mechanism is known to affect only the “nail head” region where weld shape is primarily governed by fluid flow
- Solute effects are secondary in the deep penetration “spike” region where weld shape is dominated by the keyhole characteristics



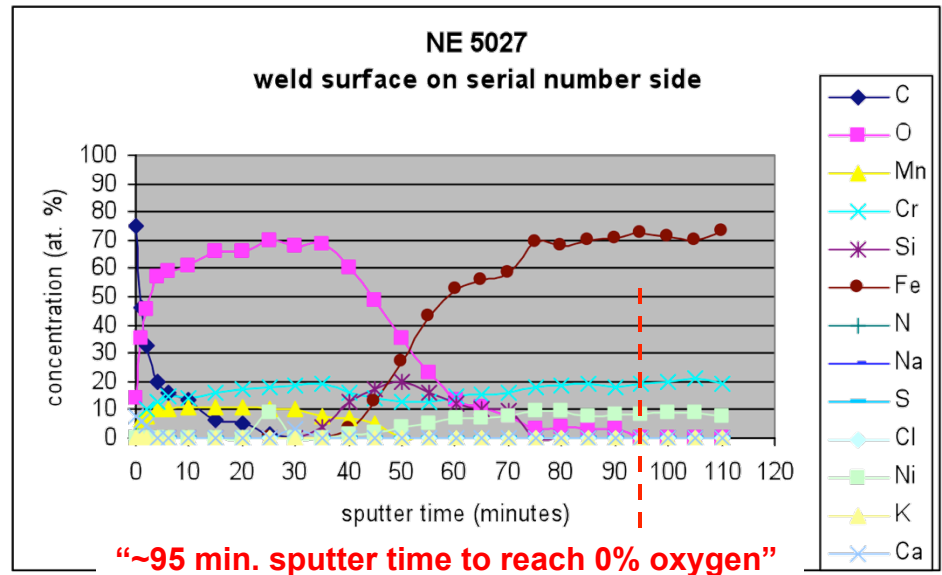
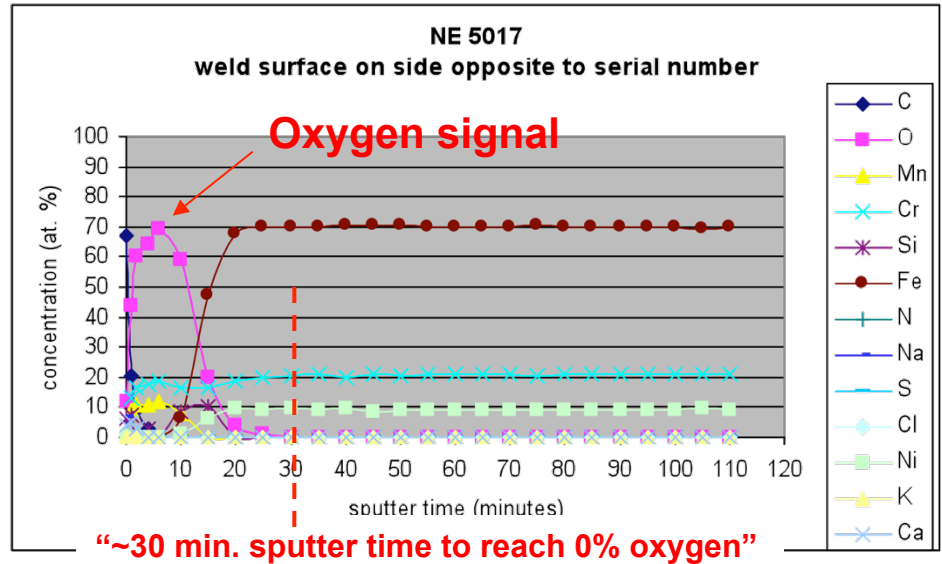
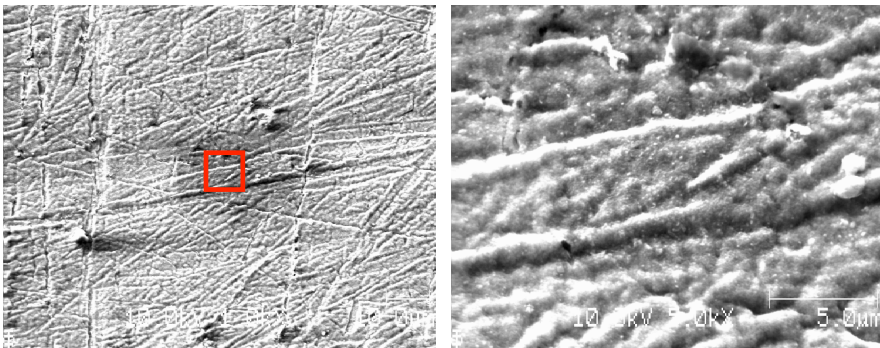


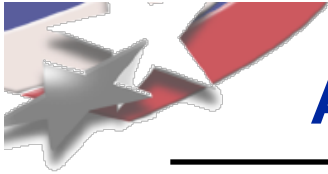
Auger analysis

- Oxide thickness varies significantly from head-to-header, and across a single header
- “sputter time to reach 0% oxygen” was used as a measure of oxide thickness.

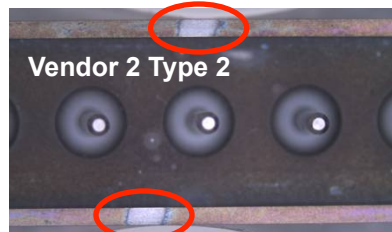


Type 1 headers 5017 and 5027 (no nitride nodules)

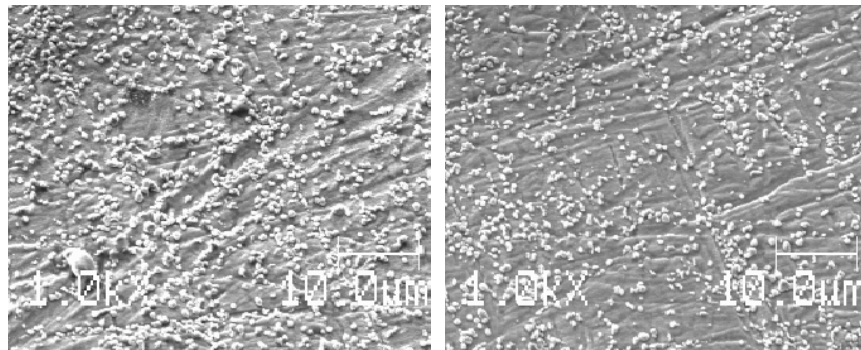




Auger analysis

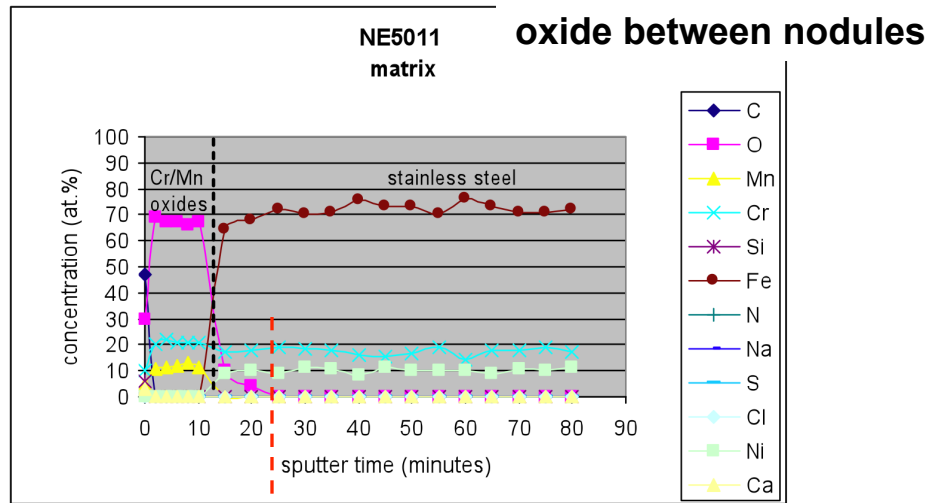
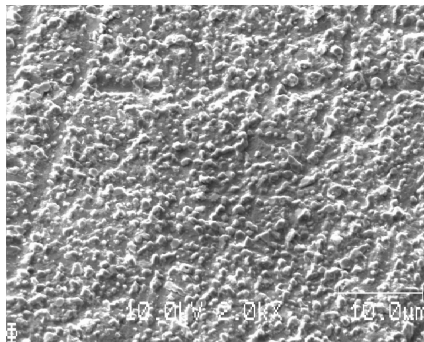


- If conditions are right for nitride nodule formation, then generally less (thinner) oxide forms

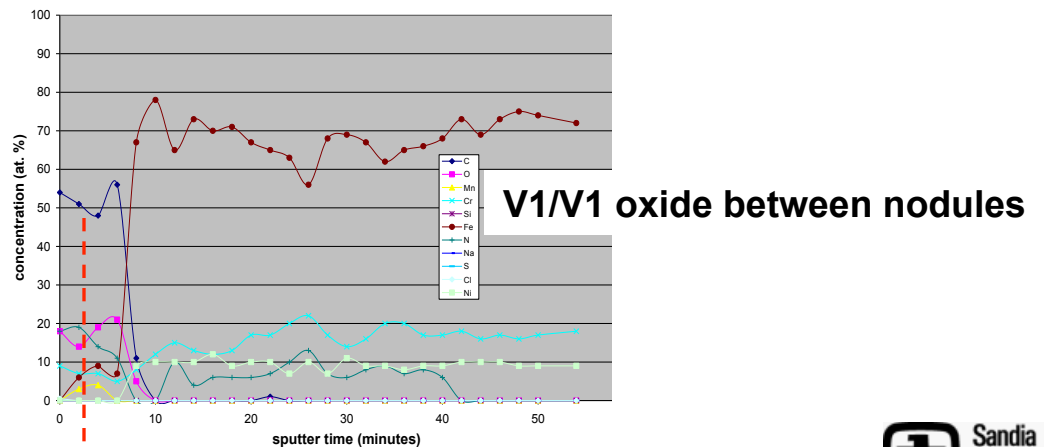


Serial number side Opposite serial number

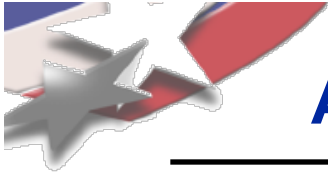
Vendor 2 header (above)
Vendor 1 header (below) –
Generally greater nitride coverage



“~25 min. sputter time to reach 0% oxygen”

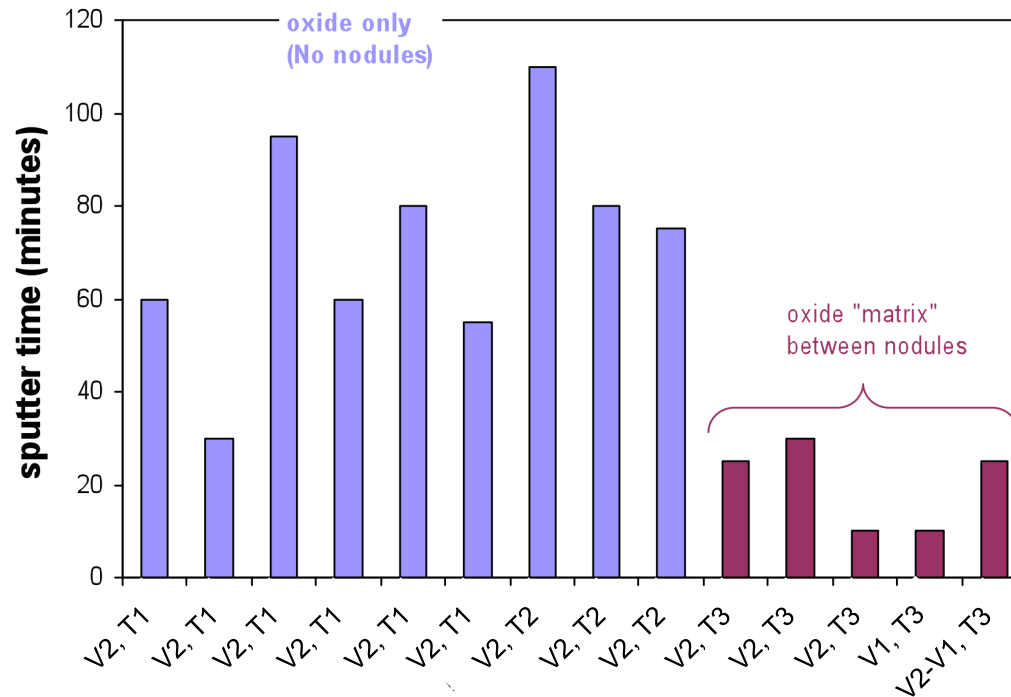


“~10 min. sputter time to reach 0% oxygen”

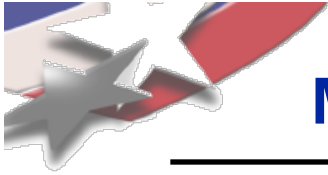


Auger analysis

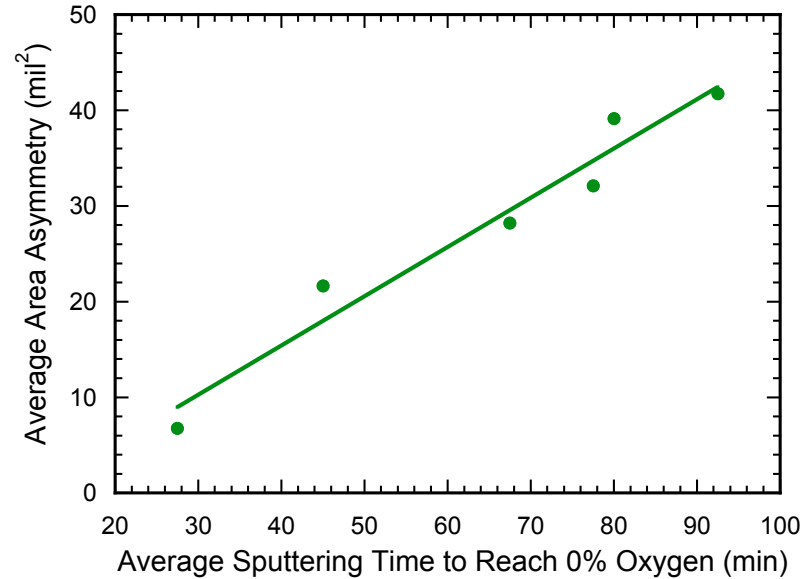
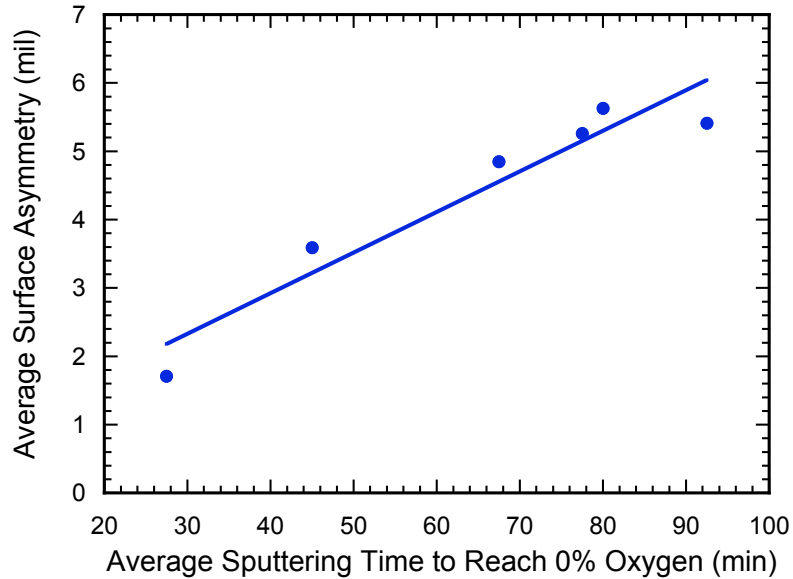
Sputter Time to Reach 0% Oxygen



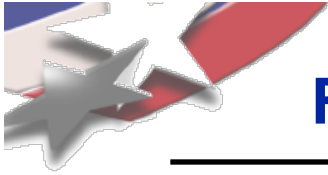
- Assuming the surface oxygen is incorporated into the weld, the oxide thickness, as measured by sputtering time, was used to assess effects of oxygen on weld characteristics



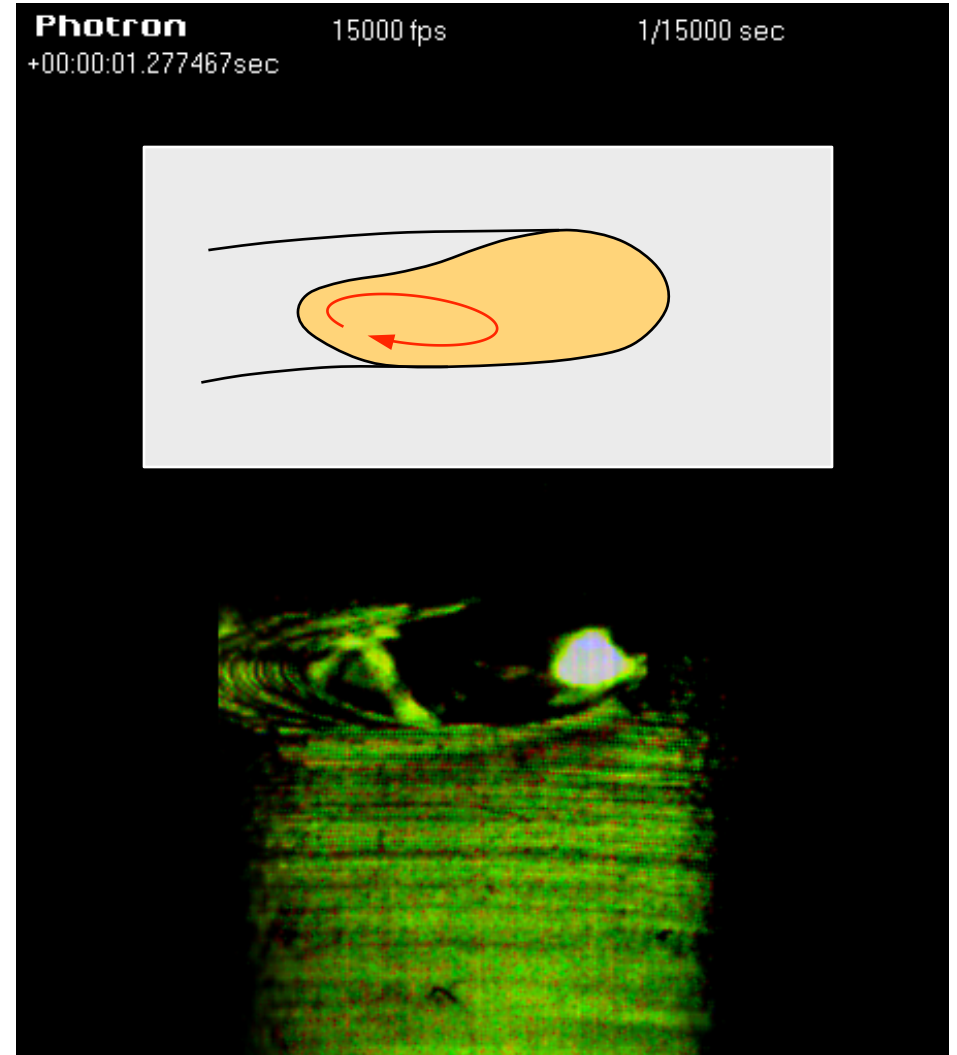
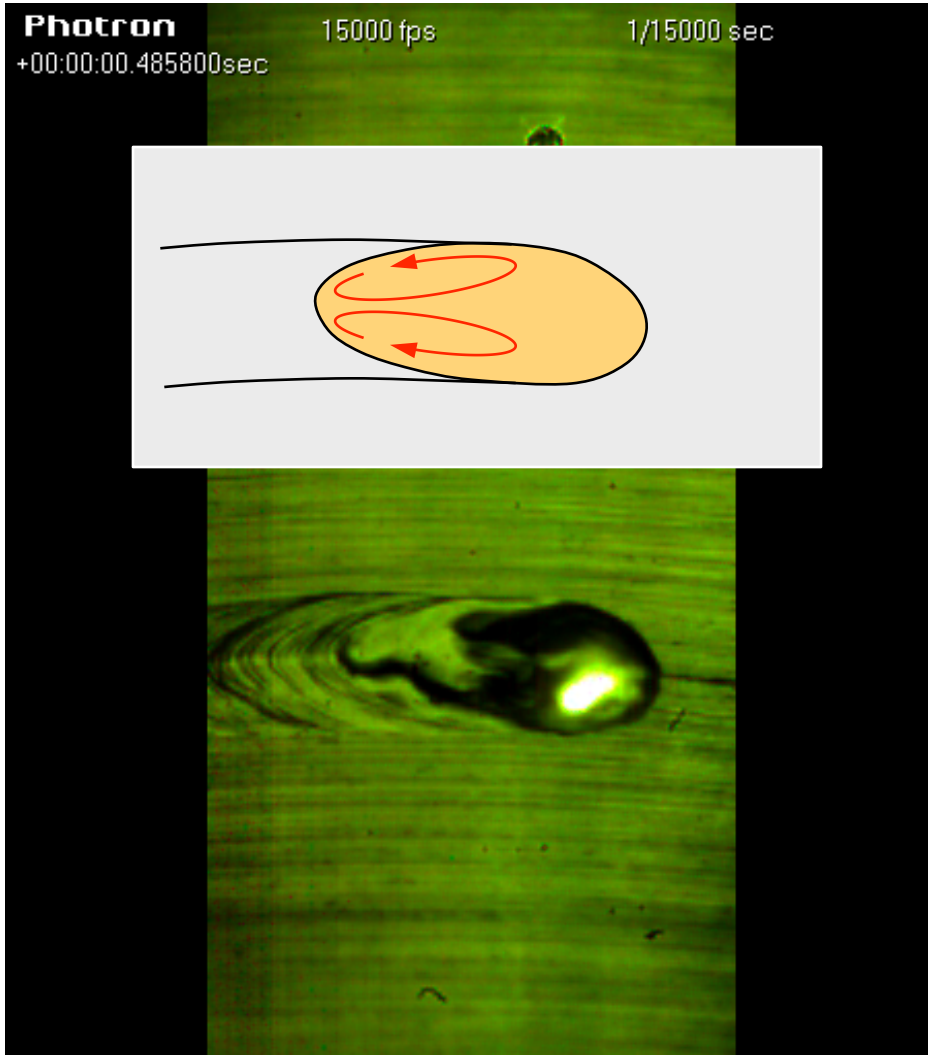
Mechanism and implications for asymmetry

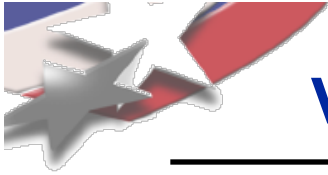


- In terms of average quantities, asymmetry correlates with the oxygen content as measured by Auger spectroscopy
- We believe that oxygen is the principal species responsible for the asymmetry

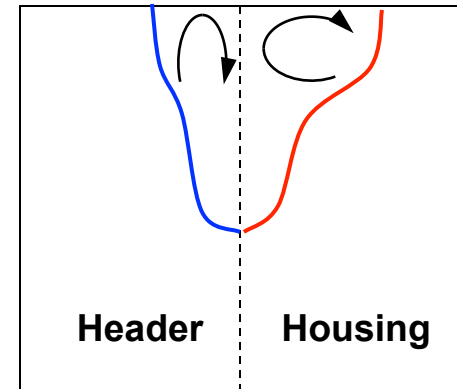
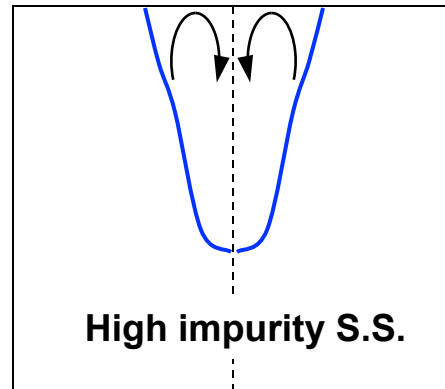
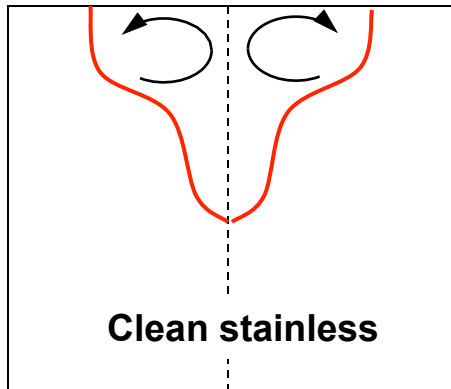


Fluid flow

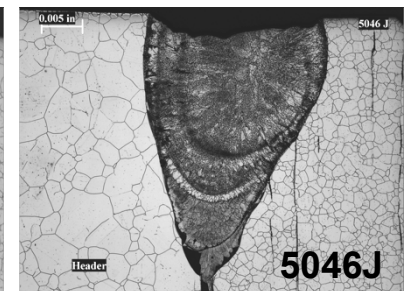
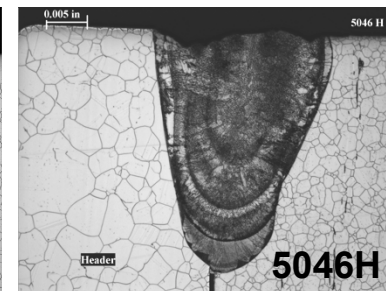
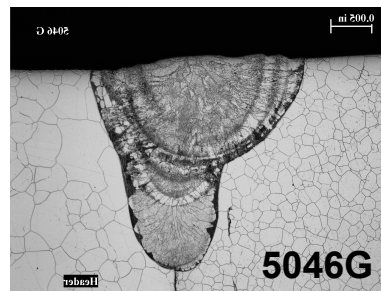
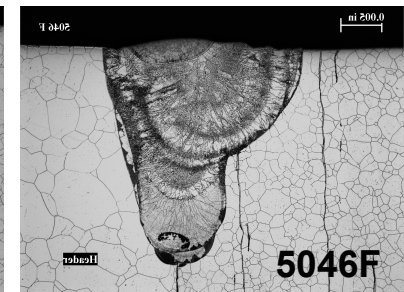
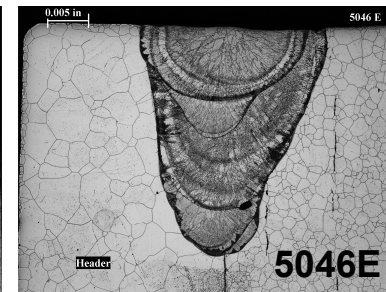
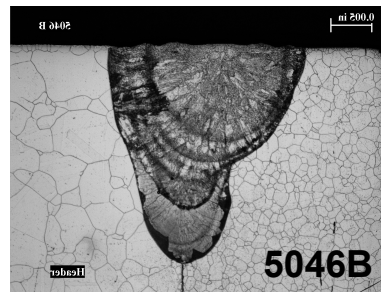


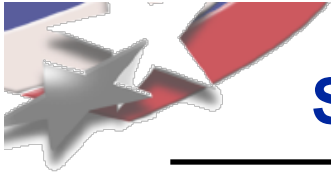


Variability



- The variable nature of the nitrogen (nodule density) and oxygen (layer depth) between parts, and across individual parts, makes definitive correlations impossible
- Examples show variation in a single Type 3 header
- It should be noted that narrow (but generally symmetric) welds are often seen with large gaps

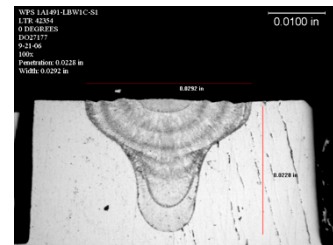
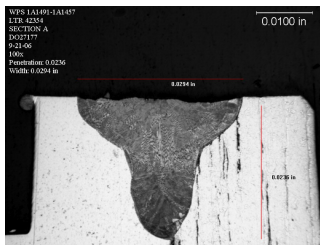




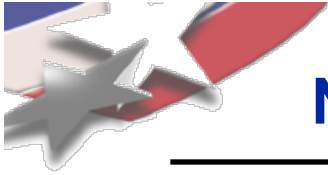
Solidification mode

Within some variance, typical modes are as follows:

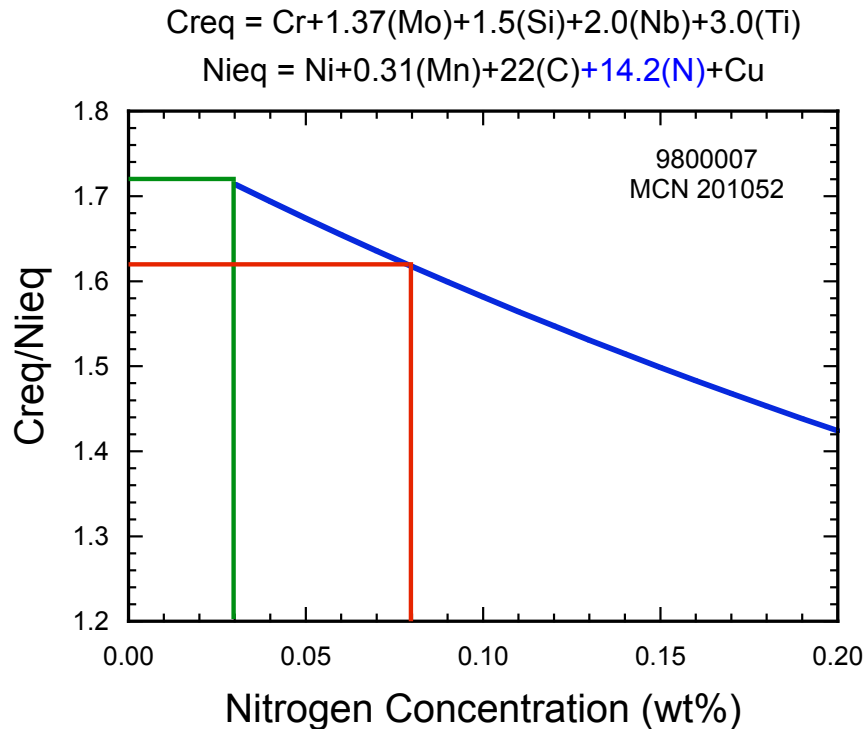
Historical Type 1:	Genuine, A-mode ranging from a few% to 100% Simulative, F-mode with minimal A-mode at periphery Recent PID, F-mode , with minimal A-mode at periphery
Vendor 1 GC Type 1:	F-mode with small amount of A-mode (usually along header fusion line)
Vendor 2 GC Type 2:	F-mode with small amount of A-mode (usually along header fusion line)
Vendor 1 GC Type 2:	A-mode , with 10-40% F-mode on housing side
Vendor 2 GC Type 2:	F-mode with small amount of A-mode (usually along header fusion line)
Vendor 1 GC Type 3:	A-mode , with 10-30% F-mode on housing side
Vendor 2 GC Type 3:	F-mode with small amount of A-mode (usually along header fusion line)



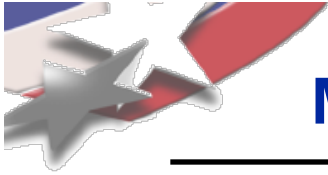
- These observations imply that the range of observations on GC headers falls within the range of observations for clean headers



Nitrogen levels in the welds



- Nitrogen content in the weld can be estimated by calculating the amount of N needed to effect a solidification mode change
 - We assume H&S Cr and Ni equivalents and that the mode change occurs at 1.62 (conservative)
 - The estimate is further conservative in that appreciable mode change was not seen in Vendor 2 headers and can also be explained by material lot (austenitic mode seen in clean WPQR samples)
 - For typical compositions, the estimate gives an incremental N of $0.08 - 0.03 = 0.05$ wt%
-
- We attempted to determine this quantity directly, but such measurements are inherently uncertain
 - We are not aware of a similar way to estimate oxygen content



Mechanical properties

TABLE 6 Effect of Elements on Strength of Austenite in Alloys Approximating AISI Type 302 Stainless Steel⁵¹

The numbers shown are coefficients for the respective elements in the following formulas, where d and t are grain diameter and twin mean-free path, respectively, in millimeters.
 $0.2\% \text{ PS (tons/in.}^2) = 4.1 + \sum (\text{element coefficient}) (\text{wt } \% \text{ element}) + 0.16 (\% \text{ ferrite}) + 0.46 (d^{-1/2})$
 $\text{TS (tons/in.}^2) = 29 + \sum (\text{element coefficient}) (\text{wt } \% \text{ element}) + 0.14 (\% \text{ ferrite}) + 0.82 (t^{-1/2})$

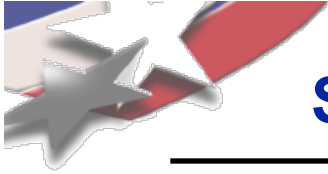
Solute	Type	Strength coefficients		
		For 0.2% proof stress	For tensile strength	
N	Interstitial	32	55	
C		23	35	
Cb	Substitutional, Ferrite Stabilizer	2.6	5.0	
Ti		1.7	3.0	
Al		.8	2.4	
Si		1.3	1.2	
V		1.2	0	
Mo		0.9	0	
W		0.3	0	
Cr		0.2	0	
Ni		Substitutional, Austenite Stabilizer	0	-0.1
Mn			0	0
Cu	0		0	
Co	0		0	

- Coefficients for nitrogen in commonly used strength equations (based on analysis of 86 heats of austenitic stainless steel) are:

$$0.2\% \text{ YS: } + 70.5 \text{ ksi/wt}\% \text{ N}$$

$$\text{UTS: } + 121.2 \text{ ksi/wt}\% \text{ N}$$

- For the 0.05 wt% increment, we expect a YS difference of 3.5 ksi (about 10% of normal annealed base metal YS) and a UTS difference of 6 ksi
- For recent welds contaminated with oxygen (to a level sufficient to alter weld shapes), we measured about a 10% relative reduction in YS and UTS and about a 5% reduction in weld ductility
- Nitrogen does not enter into ductility equations (has no statistical effects at levels well above 0.08 wt)



Summary

- Welds in GC headers meet all requirements except possibly those associated with centering
- Penetration and penetration variability appear unchanged relative to “clean” welds
- No cracking or unusual porosity were observed
- Auger analysis showed variable propensity for nitride nodules and oxide layer thickness
- Weld solidification mode falls within the range of previous headers, and appears to be controlled by base metal variance
- Weld asymmetry is prevalent in Vendor 2 headers and appears to be associated with oxygen incorporation into the weld
- Weld asymmetry require changes to inspection guidance and criteria
- Weld properties are possibly affected (strength at an estimated 10% relative level, and ductility at an estimated 5% relative level)