IAB PROJECT ABSTRACT/DESCRIPTION FORM

Project – Zero-Gap Galvanized Steel Welding

INVESTIGATORS: Ashish Dasgupta and Jyoti Mazumder

ABSTRACT/DESCRIPTION:

This project focuses on in-process quality monitoring of laser welded galvanized steel. Principles of emission spectroscopy are used to analyze light emitted from welding plasma. Mechanical analysis of welds is also performed to find actual quality. Finally a relationship between spectral data and weld quality is established that can be used to predict weld quality in real time.

PROGRESS TO DATE:

The equipment used in this study was a high power cw fiber delivered Yb:YAG. laser. Similar equipment is used at Toyota Motor Manufacturing for building auto side panels for better side impact resistance, typically the B-pillar.

Experiments were designed to study the effect of welding and sensing parameters on multiple response characteristics. We then optimized both welding and process sensing parameters using Taguchi method. Results have revealed the effect of welding defects like porosity and bead separation on recorded spectroscopy data. Using this knowledge, thresholds for predicting good and bad weld quality were established. Effort is going on toward improving quality sensing logic and developing a PC based monitoring interface for production floor use.

BENEFITS TO MEMBERS (Achieved and Anticipated)

Improved prediction of quality and reliability of welded galvanized steel parts, especially for automotive applications. Availability of science-based laser process monitoring system that will guarantee quality of processing.

MILESTONES

1) Effects of laser welding parameters on weld quality were identified.
2) Effects of weld defects on welding plasma emission were identified.
3) A relation between overall weld quality and plasma emission was established.
4) Laser wavelength and evaporation rate of material were found to be related.
5) Thresholds for predicting weld quality as good or bad were obtained.

Zero-Gap Galvanized Steel Welding

Ashish Dasgupta and Jyoti Mazumder
NSF IUCRC Spring Board Meeting
University of Michigan

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Objectives

- Study the effect of laser welding parameters on weld quality
- Study the effect of weld defects on plasma emission
- Relate plasma emission with weld quality
- Develop an in-process quality monitoring logic and system for production floor use

Taguchi DOE

Designs	Number of levels 2	3	4	5
L4 (2^3)	2-3			
L8 (2^7)	2-7			
L9 (3^4)		2-4		
L12 (2^{11})	2-11			
L16 (2^{15})	2-15			
L16 (4^5)			2-5	
L25 (5^6)				2-6
L27 (3^{13})		2-13		
L32 (2^{31})	2-31			

Designs	Number of levels 2	3
L18 (2^1 3^7)	1	1-7
L36 (2^{11} 3^{12})	1-11	2-12
L36 (2^3 3^{13})	1-3	13
L54 (2^1 3^{25})	1	3-25

- Use L9 matrix to study bead separation (gap)
- Use L18 matrix to study the effect of welding and sensing parameters

L-9 DOE

- 6 kW cw YbYAG
- Power – 2, 3, 4 kW
- Speed – 2.5, 3.75, 5 m/min
- Gas – 30, 40 50 SCFH
- Gap – 0, 0.5, 1 mm

	Number of levels			
Designs	2	3	4	5
L4 (2^3)	2-3			
L8 (2^7)	2-7			
L9 (3^4)		2-4		
L12 (2^{11})	2-11			
L16 (2^{15})	2-15			
L16 (4^5)			2-5	
L25 (5^6)				2-6
L27 (3^{13})		2-13		
L32 (2^{31})	2-31			

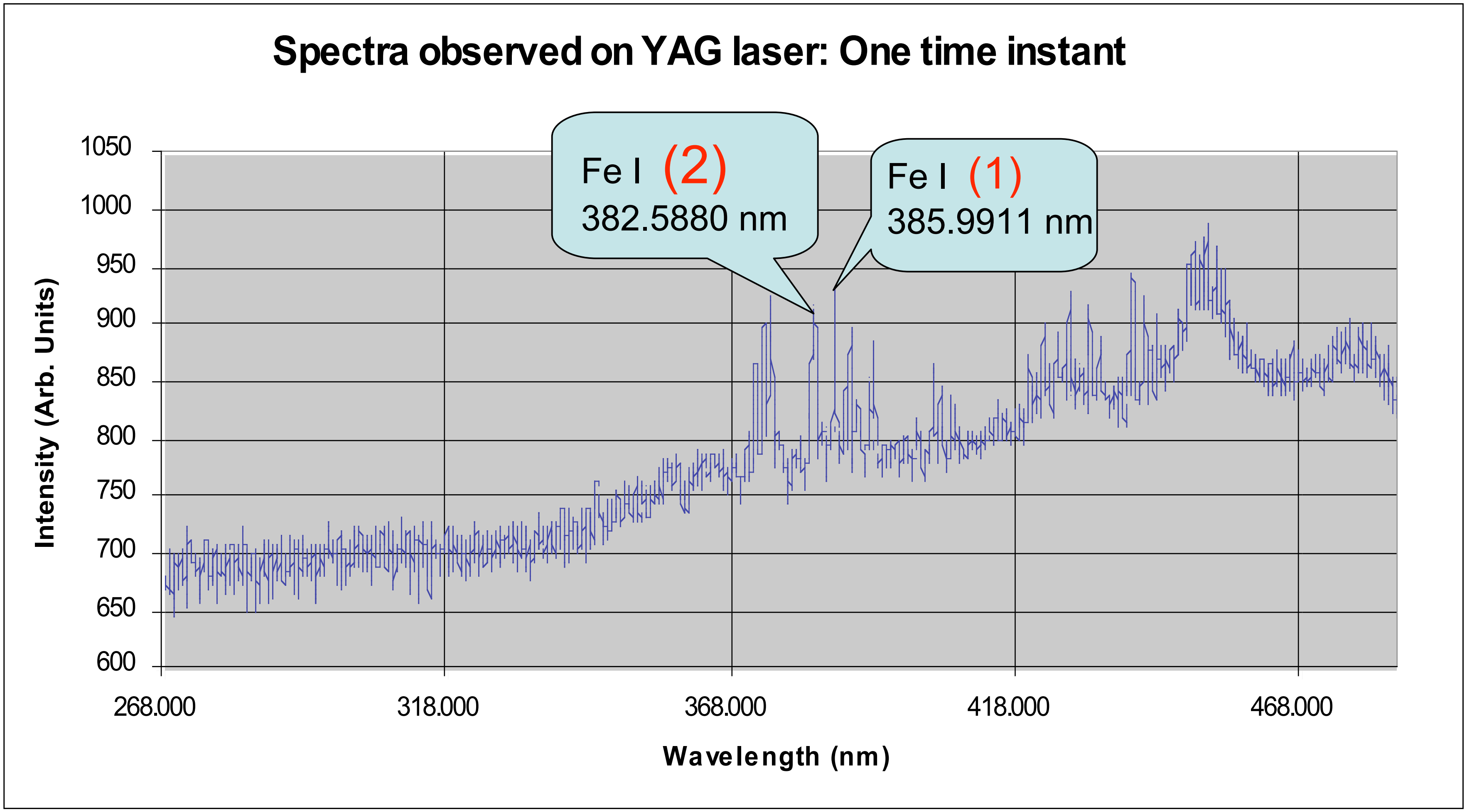
L-18 DOE

Copper Y/N	Gas Type	Laser Power	Welding Speed	Gas Flow Rate	Fiber Distance	Integration Time	Focus Position
1	1	1	1	1	1	1	1
1	1	2	2	2	2	2	2
1	1	3	3	3	3	3	3
1	2	1	1	2	2	3	3
1	2	2	2	3	3	1	1
1	2	3	3	1	1	2	2
1	3	1	2	1	3	2	3
1	3	2	3	2	1	3	1
1	3	3	1	3	2	1	2
2	1	1	3	3	2	2	1
2	1	2	1	1	3	3	2
2	1	3	2	2	1	1	3
2	2	1	2	3	1	3	2
2	2	2	3	1	2	1	3
2	2	3	1	2	3	2	1
2	3	1	3	2	3	1	2
2	3	2	1	3	1	2	3
2	3	3	2	1	2	3	1

Laser: Fiber delivery Trumpf 6 kW YbYAG

Parameter ranges: P 2, 3, 4 kW
S 2.5, 3.75, 5 m/min
Gas 30, 40, 50 SCFH
Gas type Air, Ar, He

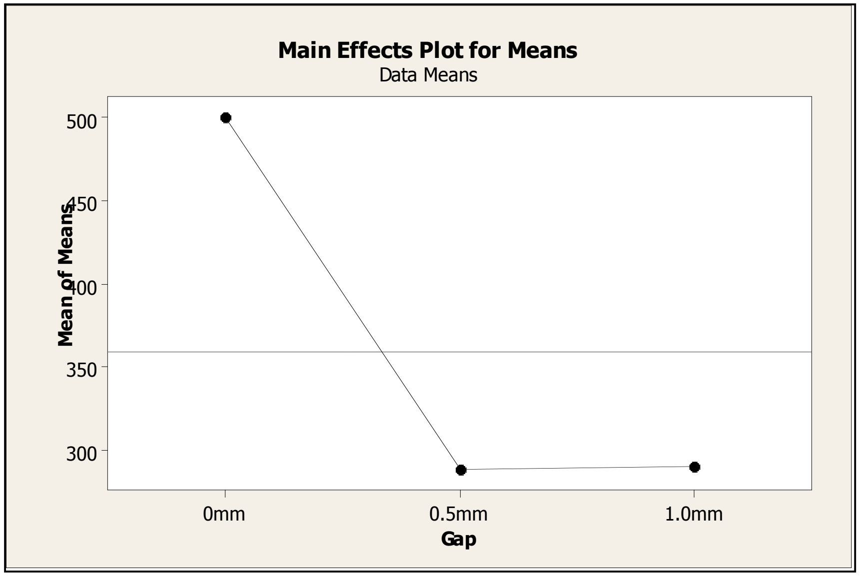
Fiber distance 35, 40, 50 mm
Integration time 10, 20, 40 ms
Focus position +0.14, 0, -0.14 mm
Copper 325 mesh Y/N



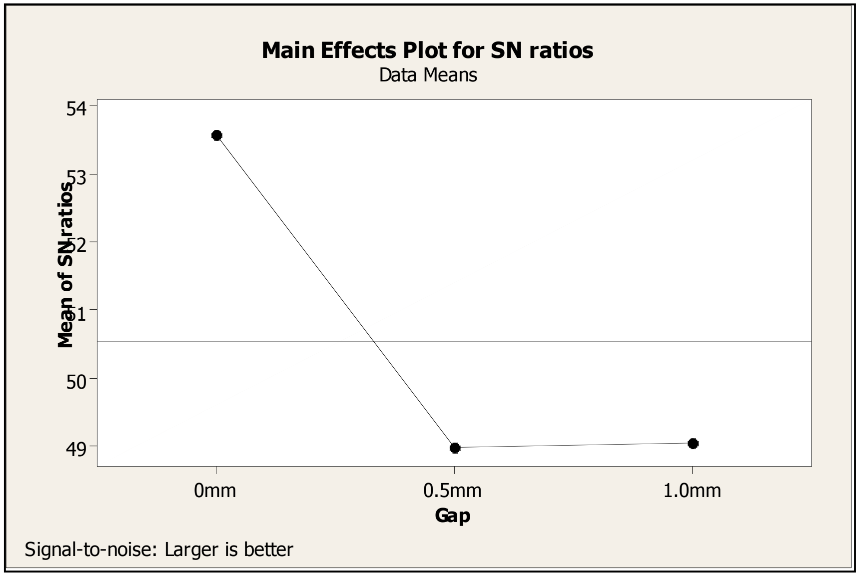
Center for Lasers and Plasmas in Advanced Manufacturing
University of Michigan

L9 – Effect of bead separation

Mean Intensity (1)

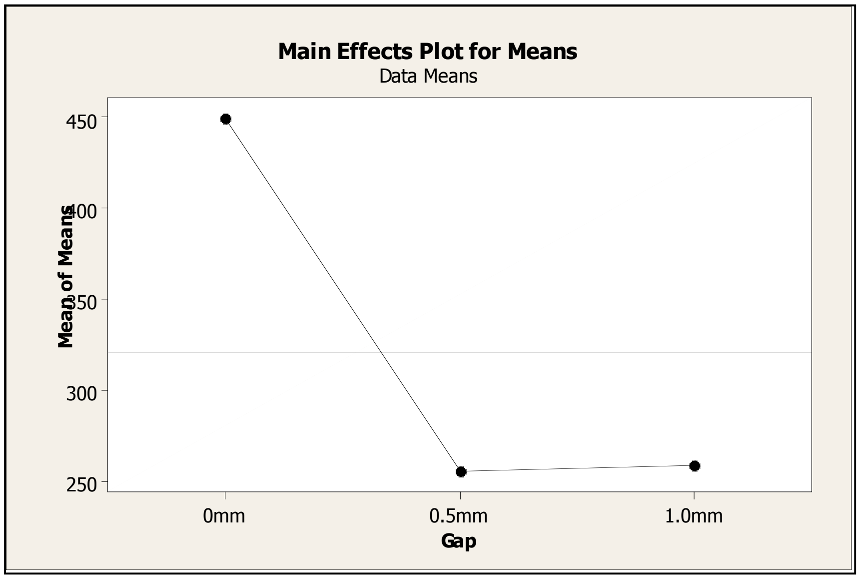


Signal-to-Noise Ratio (SNR) Intensity (1)

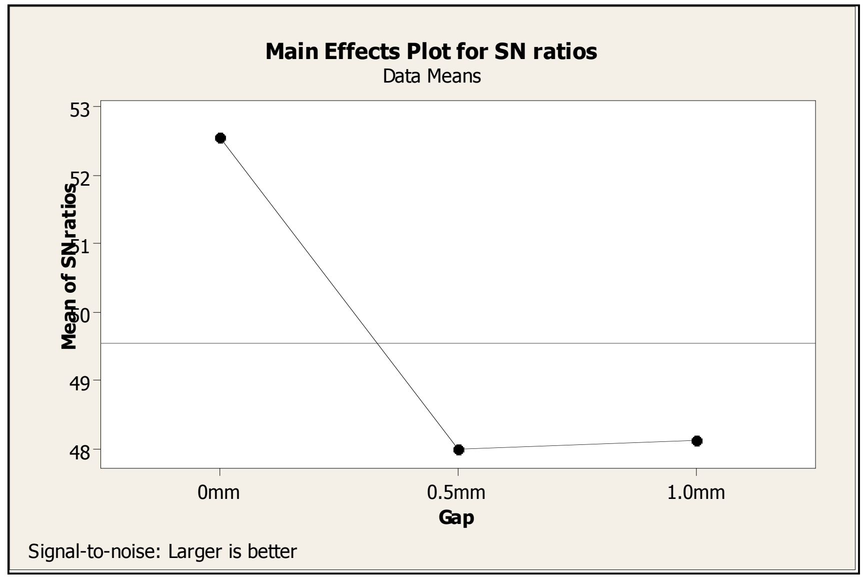


L9 – Effect of bead separation

Mean Intensity (2)

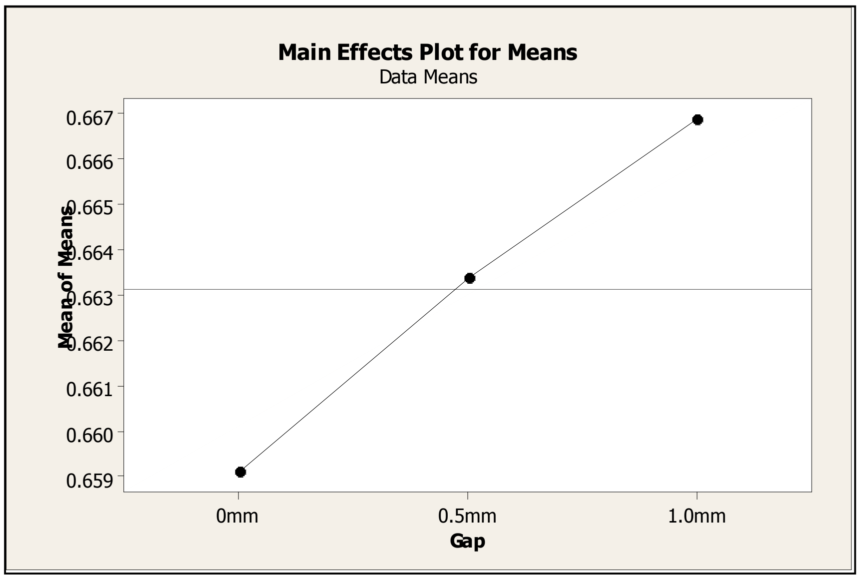


SNR Intensity (2)

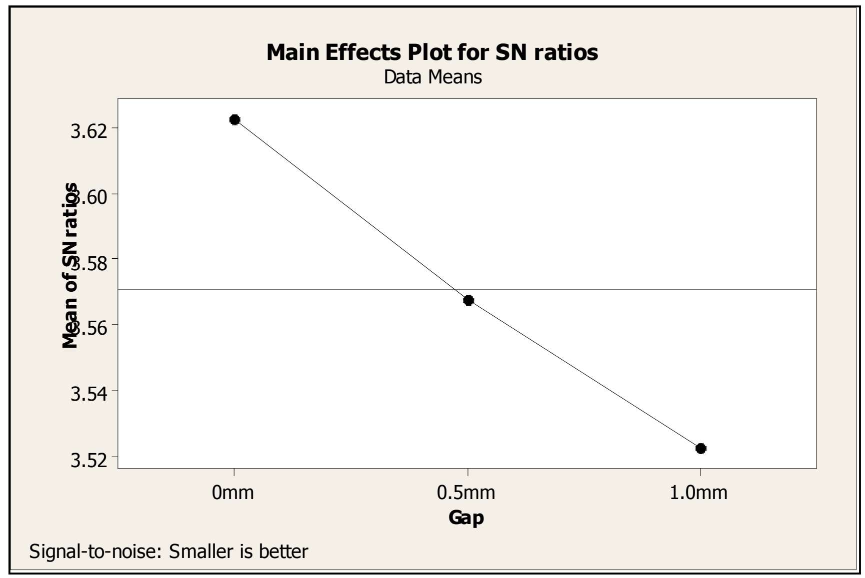


L9 – Effect of bead separation

Mean Electron Temp



SNR Electron Temp



L18 – Dimensionless QI's and TQI

LGB = larger the better criteria of quality
SMB = smaller the better criteria of quality

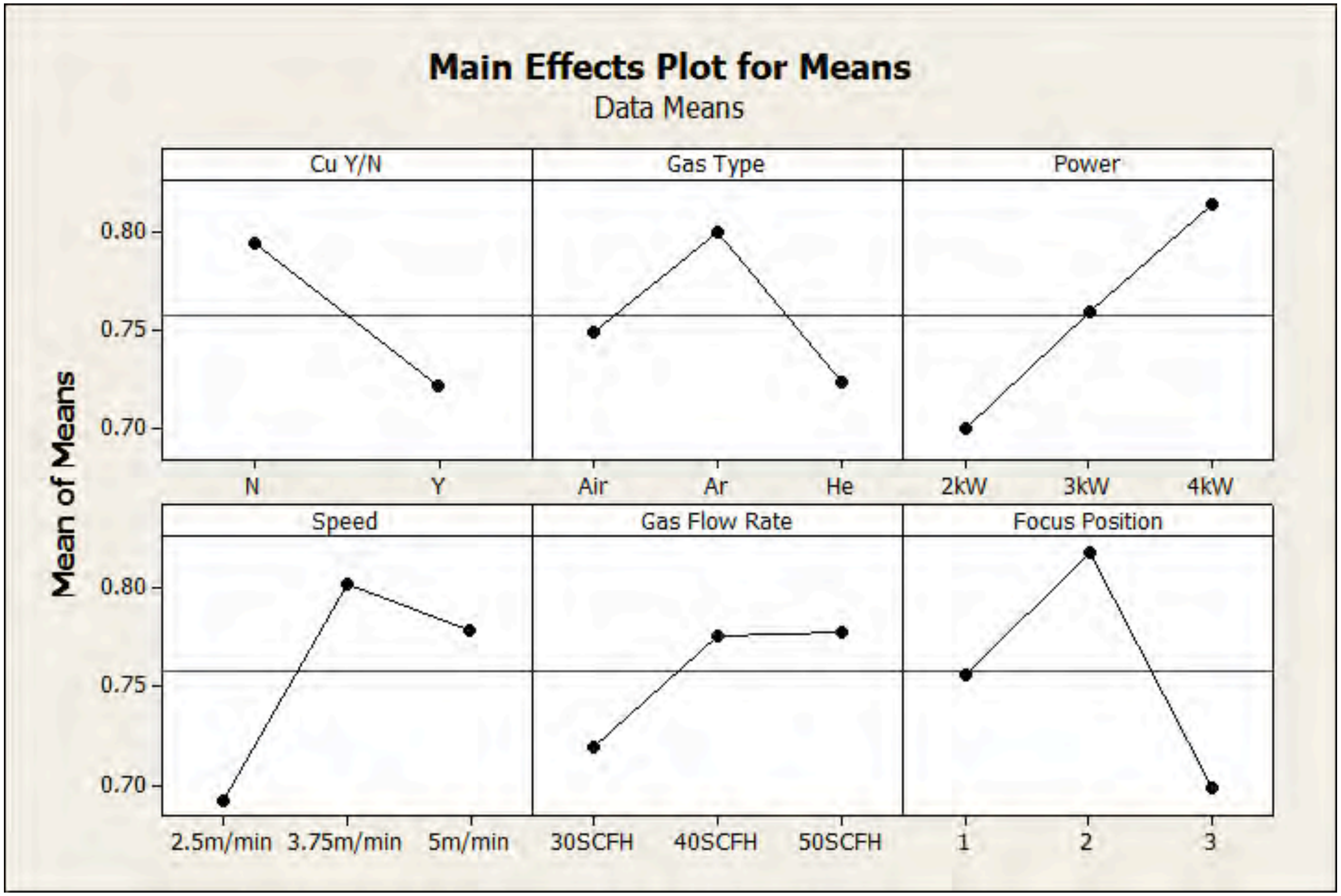
High TQI means better Quality

Weld	QI Bead Width (SMB)	QI Depth of Pen. (LGB)	QI HAZ Width (SMB)	QI %Porosity/mm (SMB)	QI UTS (LGB)	QI Elongation (LGB)	TQI (LGB)
1	0.721	0.929	0.528	0.020	0.364	0.175	**0.456**
2	0.990	0.833	0.700	1.000	0.941	0.962	**0.904**
3	0.944	0.774	0.700	1.000	0.962	0.960	**0.890**
4	0.616	0.865	0.622	1.000	0.982	0.859	**0.824**
5	0.748	0.860	0.737	1.000	0.956	0.798	**0.850**
6	0.727	0.881	0.757	1.000	1.000	1.000	**0.894**
7	0.711	0.000	0.875	1.000	0.810	0.582	**0.663**
8	0.754	0.881	0.848	1.000	0.938	0.713	**0.856**
9	0.643	0.876	0.400	1.000	0.994	0.931	**0.807**
10	1.000	0.000	1.000	1.000	0.905	0.648	**0.759**
11	0.598	0.843	0.560	1.000	0.983	0.858	**0.807**
12	0.990	0.811	0.622	0.040	0.906	0.687	**0.676**
13	0.783	0.913	0.667	1.000	0.928	0.836	**0.855**
14	0.587	0.999	0.560	0.036	0.928	0.662	**0.629**
15	0.732	0.902	0.444	1.000	0.855	0.562	**0.749**
16	0.815	0.000	0.757	1.000	0.797	0.500	**0.645**
17	0.692	0.870	0.538	0.039	0.631	0.275	**0.508**
18	0.743	0.967	0.622	1.000	0.997	0.864	**0.865**

This is simple mean, however weighted averages can also be used

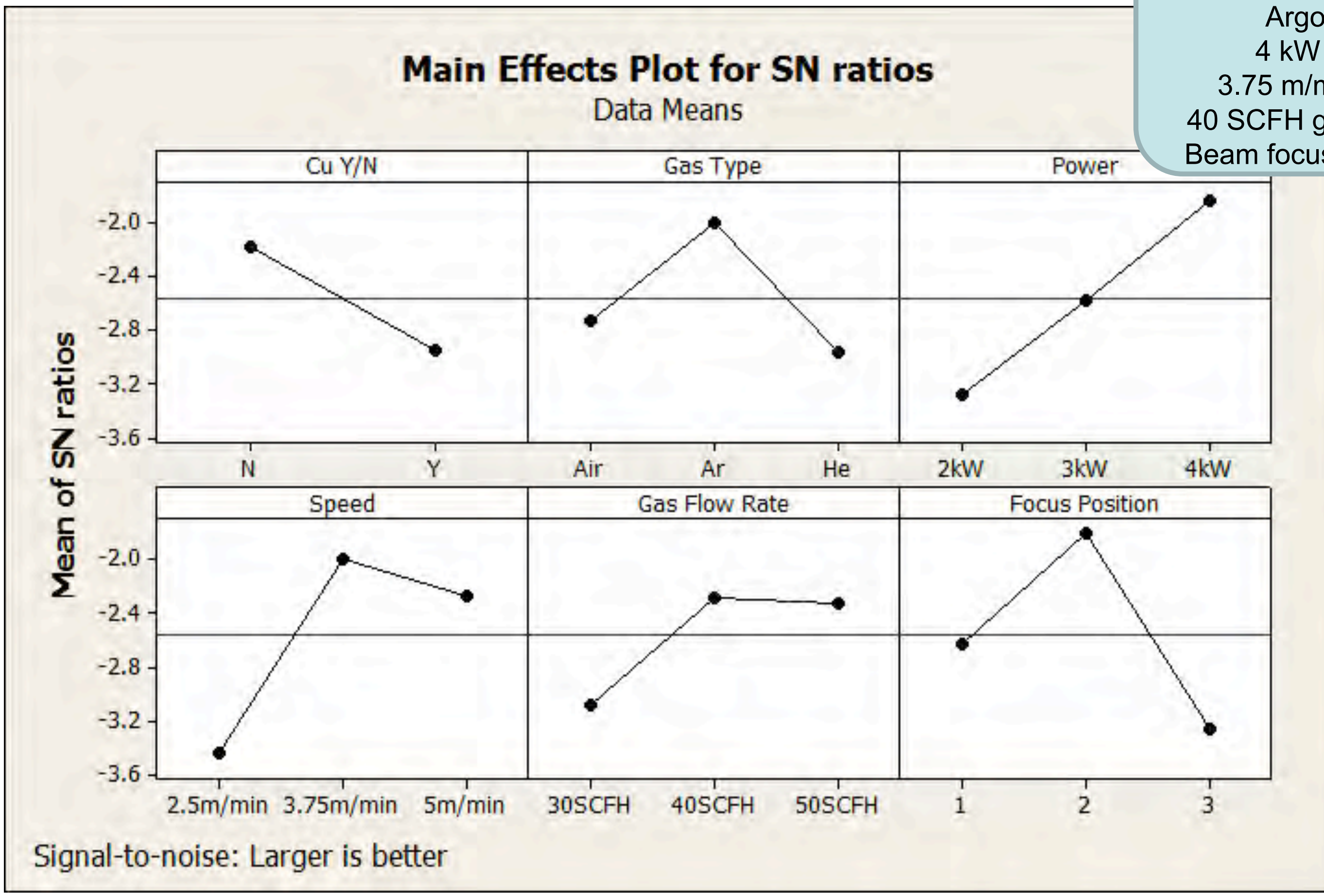
L18 – Mean TQI

(Goal – Find process parameters that produced welds with highest TQI and smallest variability)



L18 – SNR TQI

Optimal parameters:
Larger TQI is better
Cu N
Argon gas
4 kW power
3.75 m/min speed
40 SCFH gas flow rate
Beam focus on surface



Emission spectroscopy using modified Boltzmann method

J.Phys.D: 27 (1994) 268-272

- Better estimation of axis temperature
- Gaussian temperature profile is a requirement
- Suited to welding plasmas

$$T_e = \frac{E_m(2) - E_m(1)}{k \ln\left[\frac{E_m(1)}{E_m(2)} \frac{I(1) A_{mn}(2) g_m(2) \lambda(1)}{I(2) A_{mn}(1) g_m(1) \lambda(2)}\right]}$$

Data for spectral analysis

Line 1: Fe I 385.9911 nm
E = 3.2111889 eV
A = 9.70e6
g = 9
RI = 10000

Line 2: Fe I 382.5880 nm
E = 4.1543532 eV
A = 5.98e7
g = 7
RI = 1500

$$T_e = \frac{E_m(2) - E_m(1)}{k \ln\left[\frac{E_m(1)}{E_m(2)} \frac{I(1)A_{mn}(2)g_m(2)\lambda(1)}{I(2)A_{mn}(1)g_m(1)\lambda(2)}\right]} \rightarrow T_{e(Fe)} = \frac{10945.00946}{\left[\ln\left(\frac{I1}{I2}\right) + 1.318983878\right]}$$

$$T_{e(Fe)} = f(I1, I2)$$

TQI vs Spectroscopy results

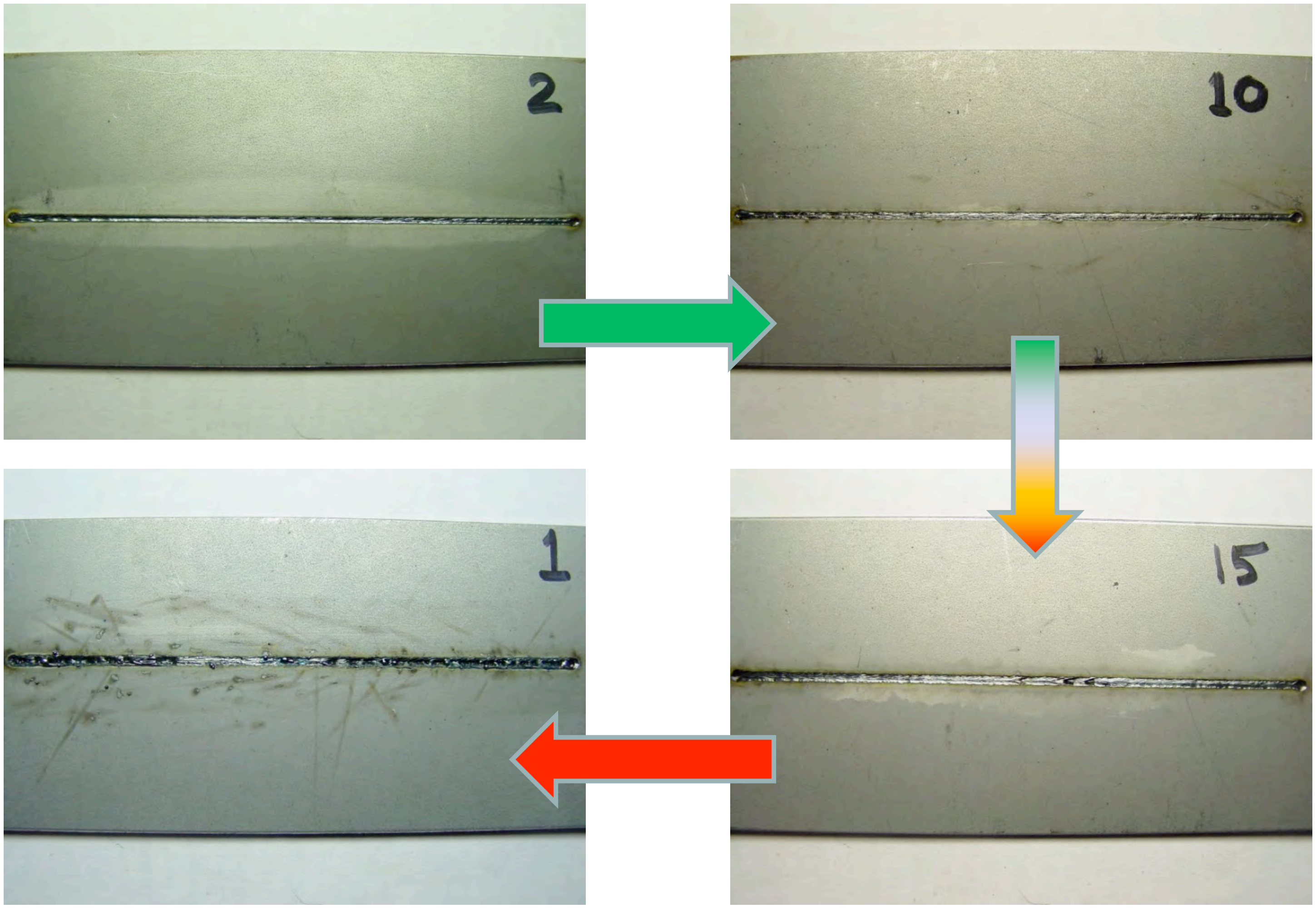
Can we predict Total Weld Quality from observed trends in spectral signals ?

Weld	CQI	Mean ET (eV)	% Std. Dev ET	% Std. Dev I(1)	Acc. Index
1	0.456	0.643	5.228	40.131	1.000
17	0.508	0.629	5.082	38.070	0.500
14	0.629	0.667	2.040	22.913	0.500
16	0.645	0.690	6.292	10.618	0.500
7	0.663	0.667	1.825	23.925	0.336
12	0.676	0.669	2.158	28.746	0.668
15	0.749	0.684	2.199	25.058	0.500
10	0.759	0.666	1.554	14.396	0.252
11	0.807	0.699	1.273	15.440	0.252
9	0.807	0.663	6.560	13.863	1.000
4	0.824	0.647	1.462	15.461	0.252
5	0.850	0.684	2.177	10.446	0.668
13	0.855	0.640	0.966	11.347	0.173
8	0.856	0.551	8.332	28.472	0.128
18	0.865	0.625	3.106	27.745	0.173
3	0.890	0.709	1.555	31.904	0.128
6	0.894	0.653	1.434	26.992	0.252
2	0.904	0.683	1.478	22.654	0.336

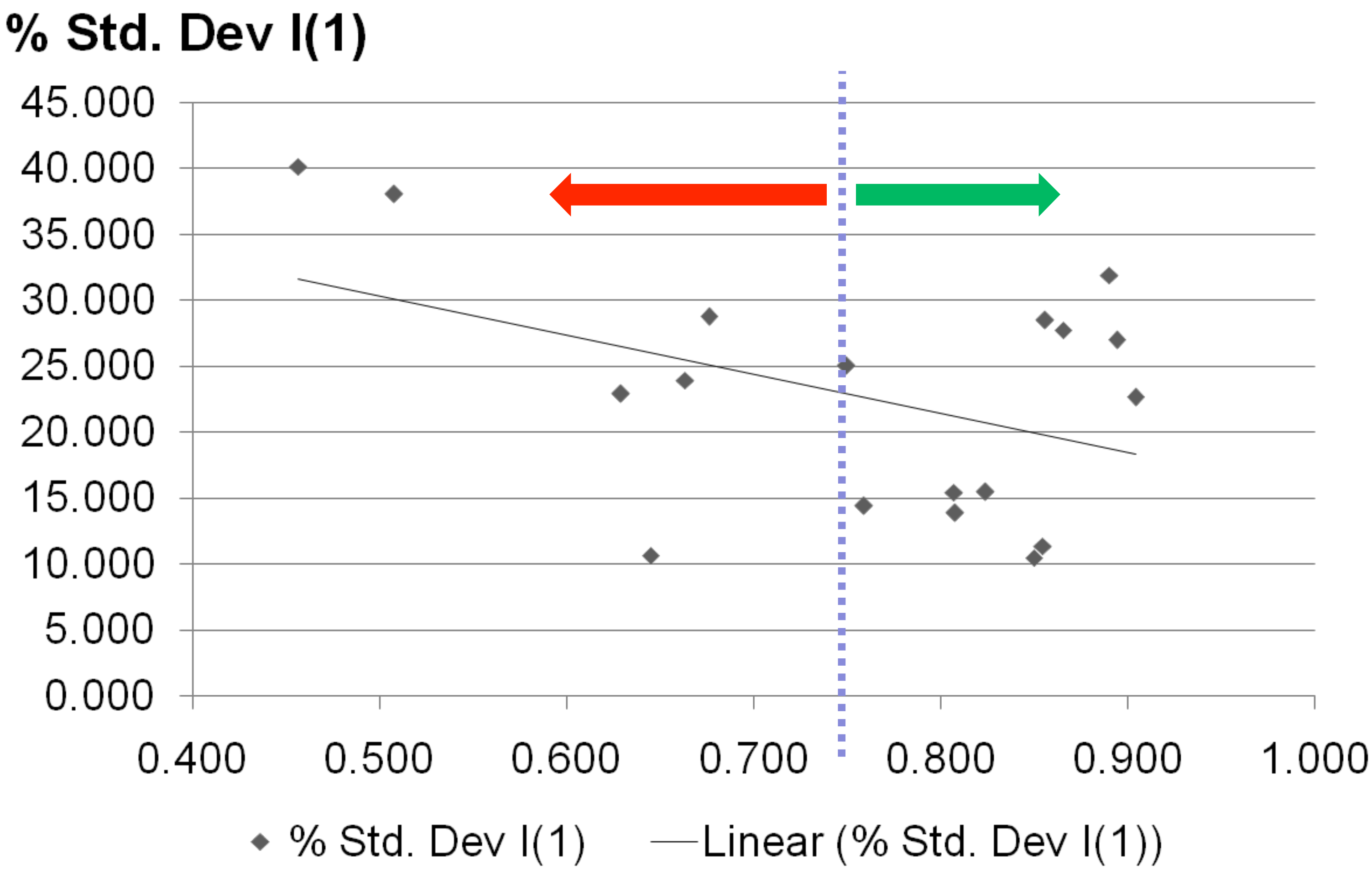
As visible in pictures

ET = Electron Temperature
I = Line intensity

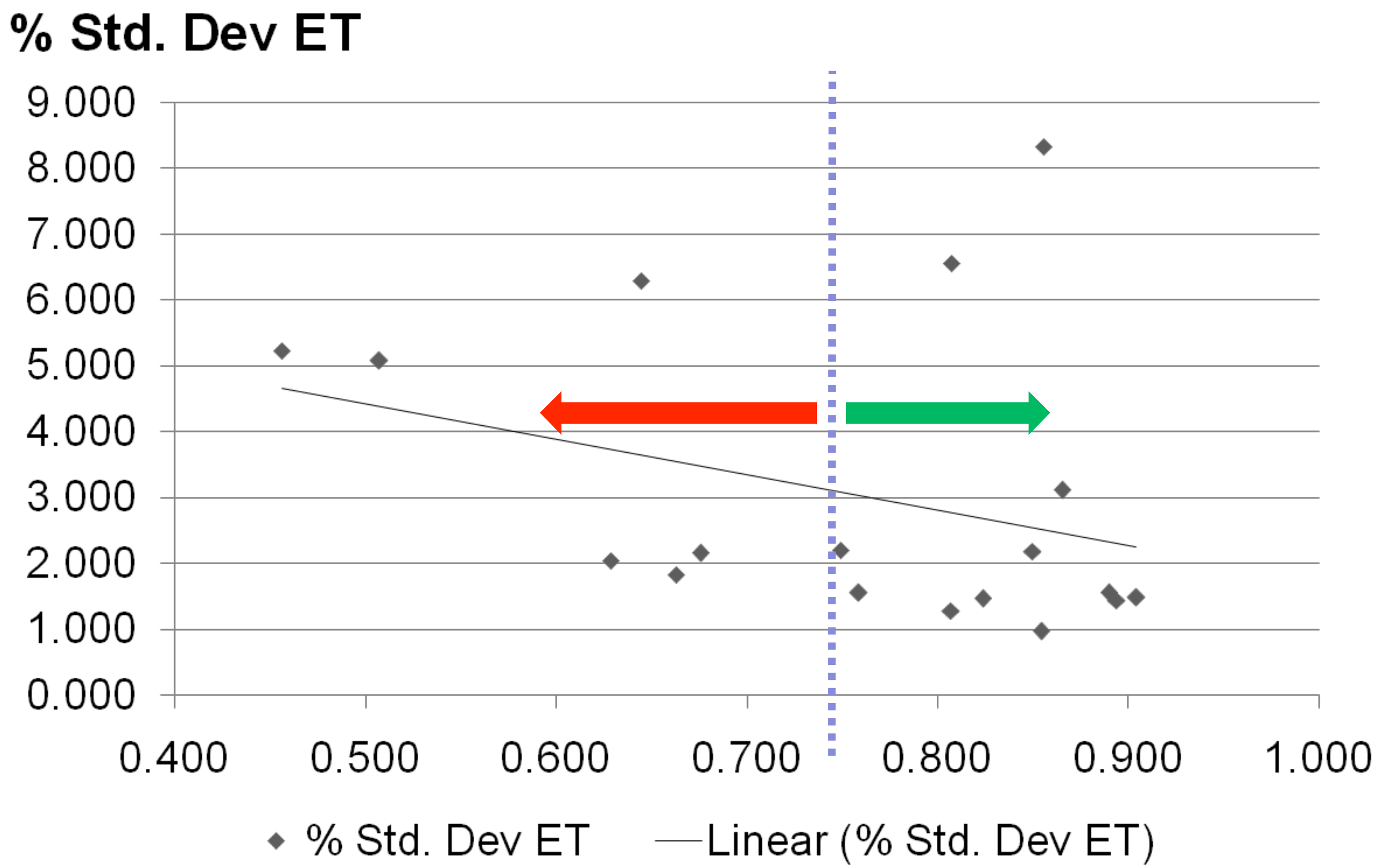
As visible weld quality



% SD I(1) vs TQI


% Std. Dev I(1)
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
0.400
0.500
0.600
0.700
0.800
0.900
1.000
% Std. Dev I(1)
Linear (% Std. Dev I(1))

% SD ET vs TQI


% Std. Dev ET
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
0.400
0.500
0.600
0.700
0.800
0.900
1.000
% Std. Dev ET
Linear (% Std. Dev ET)

Summary

- Effect of laser welding parameters on weld quality were identified.
- Effect of weld defects on welding plasma emission were identified.
- A relation between overall weld quality and plasma emission was established.
- Laser wavelength and evaporation rate of material were found to be related.
- Thresholds for predicting weld quality as good or bad were obtained.