IIW International Conference
High-Strength Materials - Challenges and Applications
2-3July 2015, Helsinki, Finland

IIW2015-15/….

Investigation of the TIG orbital welding process on tube to tube joints in titanium & 316L stainless steel thin wall tubes

R. French[1,a], H. Marin-Reyes[1,b]

[1] The University of Sheffield, Physics and Astronomy Department, United Kingdom

[a]r.s.french@sheffield.ac.uk, [b]h.marin-reyes@sheffield.ac.uk

Abstract

TIG welding is a well-established joining process and offers the user flexibility to weld a large range of materials. DC TIG welding provides the cleanest weld without sparks or spatter. However, ultra-thin wall tube to tube joining is challenging. This because of the wide range of variables needed to accurately control each part of the weld process. Generally the accuracy of the weld system, it's slope times, the arc control circuit, rotation speed of the orbital head, electrode angle and electrode material type, dictates success. This investigation will report these variables using the IP50 Heat Management System (IP50-HMS) while performing TIG orbital autogenous butt welds on tube joints in titanium and 316L stainless steel very thin wall tubes. Metallographic observations performed on a ZEISS Axio Imager M2m microscope for detailed observations show no structural or geometrical imperfections in the weld bead. For the microhardness tests, tests have been performed according to standard BS EN 1043-2 [1]. Calculation of heat input was based on arc voltage and welding current measurements for several titanium outer diameters (OD) and wall thickness sizes to allow comparison with more conventional TIG arc welds on the same materials.

Keywords: *Stainless Steel, Titanium, Weld Joining, HAZ, Metallurgy, Heat Input*

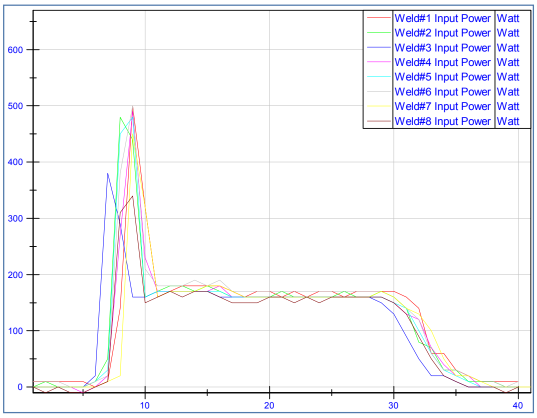
1. Introduction

- Vbc HMS Interpulse Technology description

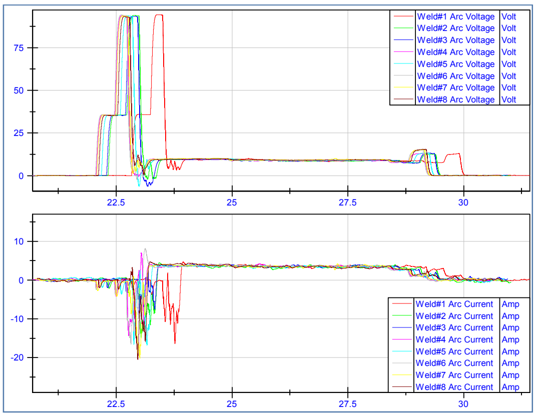
- Micro tube welding challenges, terminology.

2. Arc Voltage and Arc Current Measurements for Heat Input calculations

CP2 Titanium Tube-Tube weld joints: 3.175mm OD, 0.2mm Wall



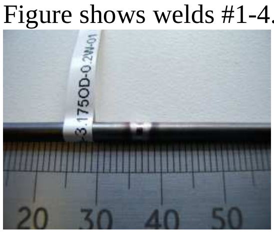
(a)



(b)

Figure. (a) Input Active Power Measurements of 8 TT weld joints with Fluke 437-II, (b) Arc voltage and arc current of welds #1-8 with NI PXI System

Plots shown in Figure were obtained while welding two CP2 Titanium tubes of 3.175mm OD and 0.2mm wall. Figure shows welds #1-4.



(a|)

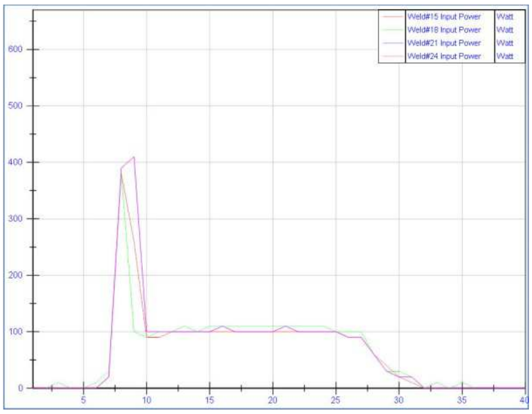
(b)

(c|)

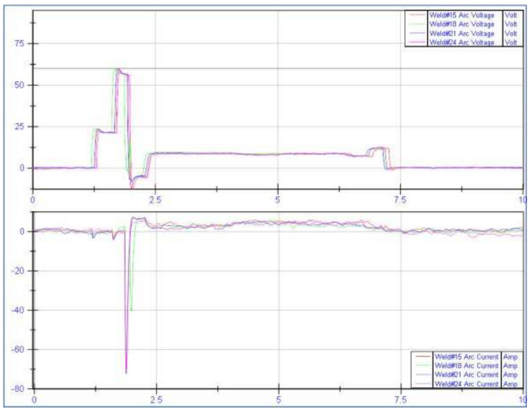
(d)

Figure. (a)-(d) CP2 Titanium Tube-Tube weld joints: 3.175mm OD, 0.2mm Wall

CP2 Titanium Tube-Tube weld joints: 2.275mm OD, 0.125mm Wall



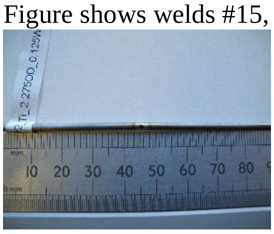
(a)



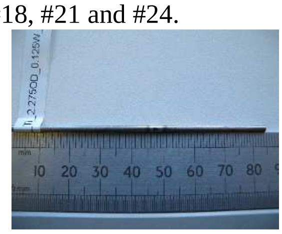
(b)

Figure. (a) Input Active Power Measurements of 4 TT weld joints with Fluke 437-II, (b) Arc voltage and arc current of welds #15, #18, #21 and #24 with NI PXI System

Plots shown in Figure were obtained while welding two CP2 Titanium tubes of 2.275mm OD and 0.125mm wall. Figure shows welds #15, #18, #21 and #24.



(a|)



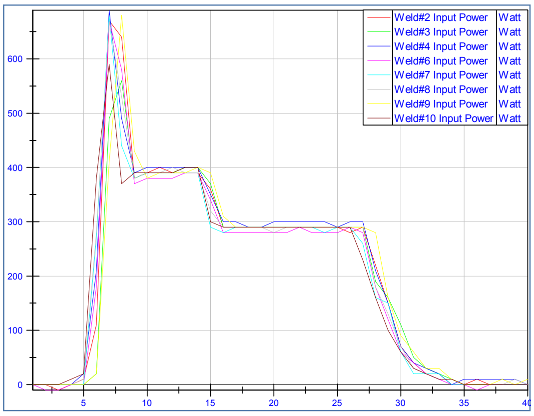
(b)

(c|)

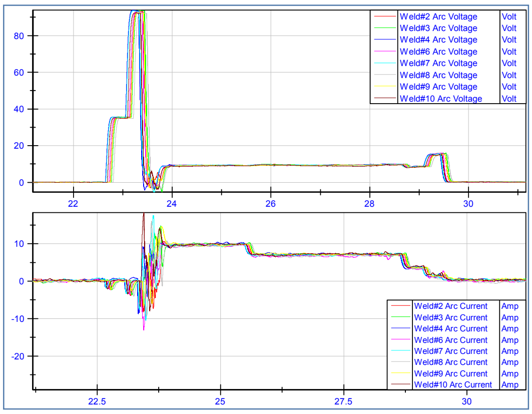
(d)

Figure. (a)-(d) CP2 Titanium Tube-Tube weld joints: 2.275mm OD, 0.125mm Wall

316L Stainless Steel Tube-Tube weld joints: 3.175mm OD, 0.72mm Wall



(a)



(b)

Figure. (a) Input Active Power Measurements of 8 TT weld joints with Fluke 437-II), (b) Arc voltage and arc current of welds #2-4 and #6-10 with NI PXI System

Plots shown in Figure were obtained while welding two 316L stainless steel tubes of 3.175mm OD and 0.72mm wall. Figure shows welds #2-4 and #6.

(a|)

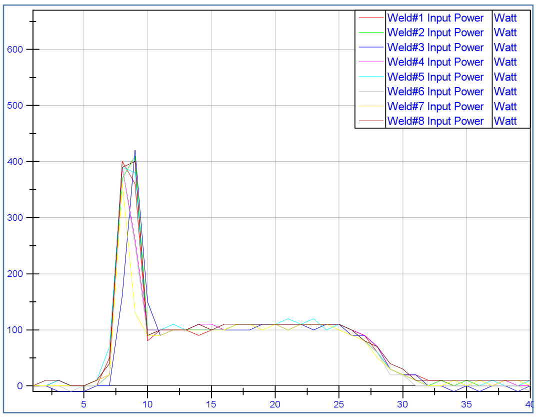
(b)

(c|)

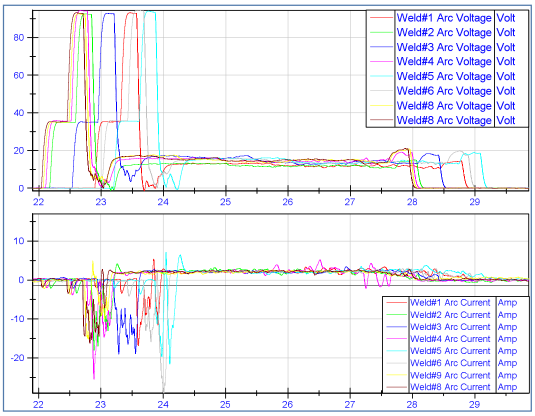
(d)

Figure. (a)-(d) 316L SS Tube-Tube weld joints: 3.175mm OD, 0.72mm Wall

316L Stainless Steel Tube-Tube weld joints: 2mm OD, 0.125mm Wall



(a)

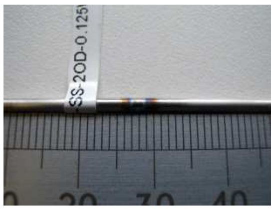


(b)

Figure. (a) Input Active Power Measurements of 8 TT weld joints with Fluke 437-II, (b) Arc voltage and arc current of welds #1-8 with NI PXI System

Plots shown in Figure were obtained while welding two 316L stainless steel tubes of 2mm OD and 0.125mm wall. Figure shows welds #1-4.

(a|)



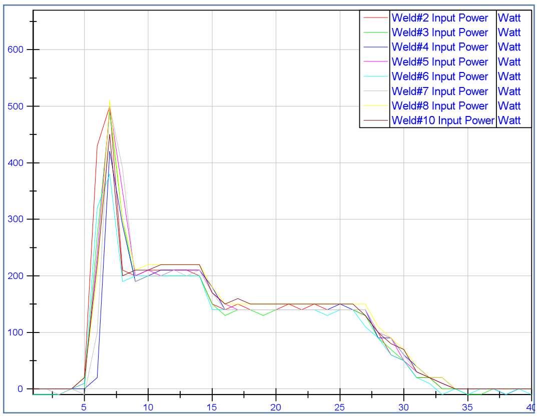
(b)

(c|)

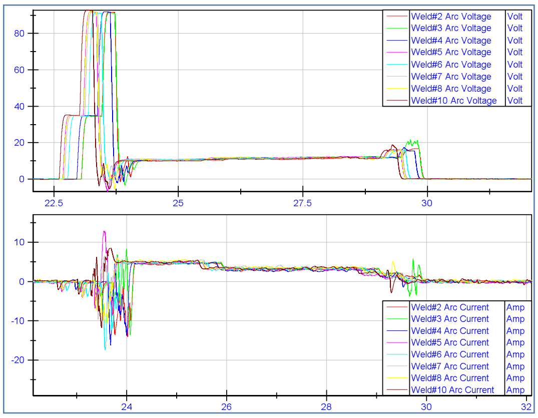
(d)

Figure. (a)-(d) 316L SS Tube-Tube weld joints: 2mm OD, 0.125mm Wall

316L Stainless Steel Tube-Tube weld joints: 3.175mm OD, 0.22mm Wall



(a)



(b)

Figure. (a) Input Active Power Measurements of 8 TT weld joints with Fluke 437-II, (b) Arc voltage and arc current of welds #2-8 and #10 with NI PXI System

Plots shown in Figure were obtained while welding two 316L stainless steel tubes of 3.175mm OD and 0.22mm wall. Figure shows welds #2-5.

(a|)

(b)

(c|)

(d)

Figure. (a)-(d) 316L SS Tube-Tube weld joints: 3.175mm OD, 0.22mm Wall

3. Heat Input Calculations

Heat input is calculated as the ratio of the power to the weld head travel speed [2] as shown in equation (1).

$$\text{Heat Input} = \frac{60 \cdot V \cdot I}{S}\ [\text{J/mm}] \qquad (1)$$

Where,

V = Average arc voltage [volts]

I = Average arc current [amperes]

S = Travel speed [mm/min]

Table 1. Heat Input of 316L Stainless Steel Tube welds

Tube OD [mm]	2	3.175	3.175
Tube Wall [mm]	0.125	0.220	0.72
Arc Voltage [Volt]	15.67	13.27	9.85
Arc Current [Amp]	2.06	3.37	6.85
Speed [RPM]	29.5	20	18
Heat Input [J/mm]	10.44	13.43	22.55

Table 2. Heat Input of 316L Stainless Steel Tube-Tube joints

Tube OD [mm]	2	3.175	3.175
Tube Wall [mm]	0.125	0.220	0.72
Arc Voltage [Volt]	13.35	7.09	5.01
Arc Current [Amp]	2.11	3.66	10.10
Speed [RPM]	29.5	20	20
Heat Input [J/mm]	9.11	7.80	15.22

Table 3. Heat Input of CP2 Tube welds

Tube OD [mm]	2.275	3.175
Tube Wall [mm]	0.125	0.2
Arc Voltage [Volt]	10.21	10.80
Arc Current [Amp]	2.12	3.72
Speed [RPM]	29.5	20
Heat Input [J/mm]	6.15	12.07

Table 4. Heat Input of CP2 Tube-Tube joints

Tube OD [mm]	2.275	3.175
Tube Wall [mm]	0.125	0.2
Arc Voltage [Volt]	8.58	8.87
Arc Current [Amp]	2.48	3.34
Speed [RPM]	29.5	18
Heat Input [J/mm]	6.06	9.89

4. Tensile Tests

Tensile tests on 3 samples have been performed on a UTS tensile test machine equipped with auto-tightening grips and a 200 kN load cell. Elongation has been measured when possible with an extensometer. One pin has been inserted at each extremity of the samples to avoid crushing. Strength has been estimated on the average of the nominal diameter and wall thickness of each pipe.

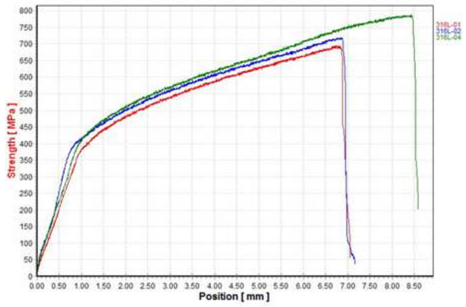


Figure 1. Graph showing stress against displacement for 316L SS 2 mm OD 0.125 mm wall tube samples

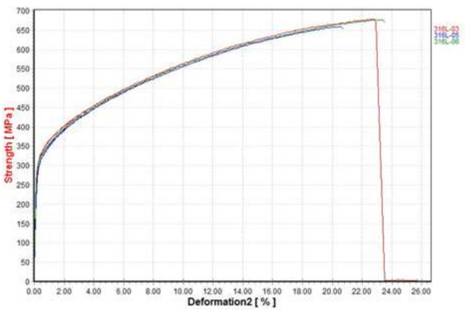


Figure 1. Graph showing stress against deformation for 316L SS 3.175 mm OD 0.22 mm wall tube samples

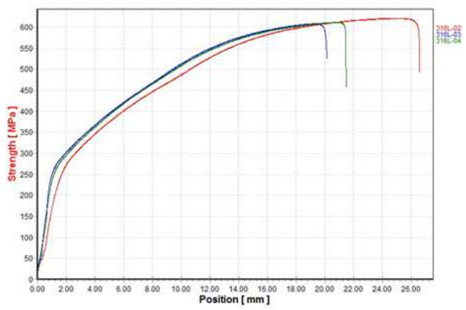


Figure 1. Graph showing stress against displacement for 316L SS 3.175 mm OD 0.72 mm wall tube samples

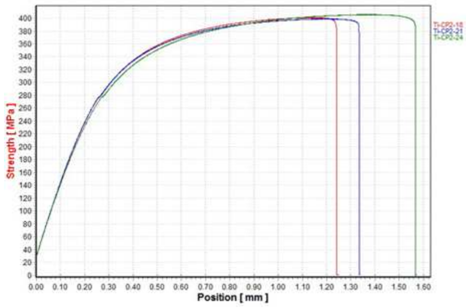


Figure 1. Graph showing stress against displacement for CP2 Ti 2.275 mm OD 0.125 mm wall tube samples

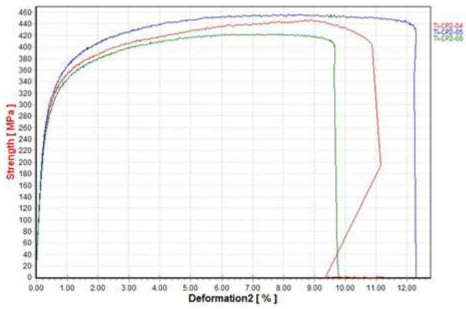


Figure 1. Graph showing stress against deformation for CP2 Ti 3.175 mm OD 0.2 mm wall tube samples

5. Metallographic observations

Cross-sectional observations have been performed on a polished and etched specimens randomly sectioned at approximate maximum diameter (see Figures 1-5).

Figure 1. Cross-sectional observations 316L SS 2 mm OD 0.125 mm wall tube sample. Original magnification: 500 x: Detail of the base material

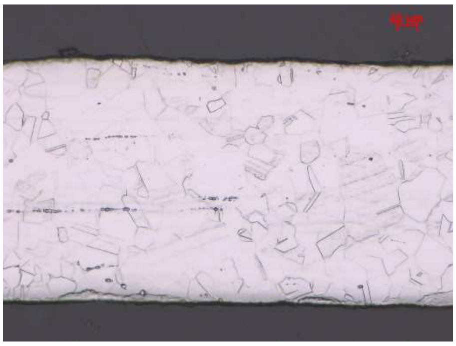


Figure 1. Cross-sectional observations 316L SS 3.175 mm OD 0.22 mm wall tube sample. Original magnification: 500 x: Detail of the base material

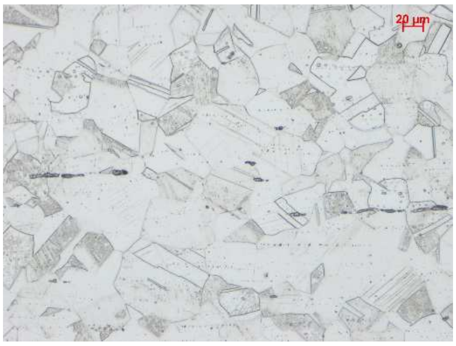


Figure 1. Cross-sectional observations 316L SS 3.175 mm OD 0.72 mm wall tube sample. Original magnification: 500 x: Detail of the base material

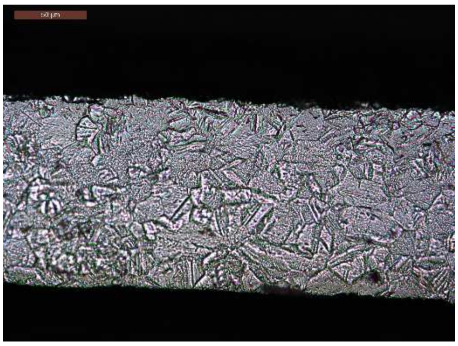


Figure 1. Cross-sectional observations CP2 Ti 2.275 mm OD 0.125 mm wall tube sample. Original magnification: 500 x: Detail of the base material

6. Heat-affected zone (HAZ)

The adjacent heat affected zone (HAZ) has been measured on 316L stainless steel Tube welds of 3.175mm OD and 0.220mm Wall as shown in Figure.

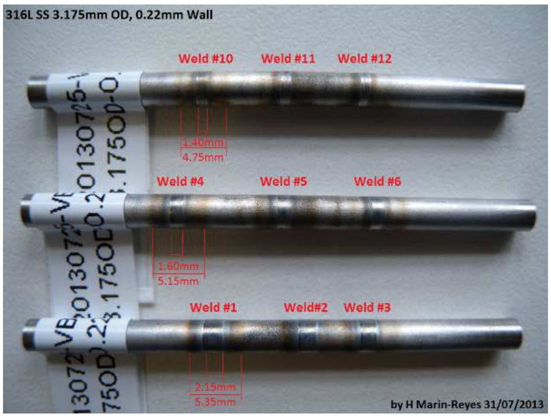


Figure. HAZ measurements

Table. Factors affecting HAZ

Standard Tube Type	316L SS			**Weld #**	**10**	**11**	**12**	**Average**
OD [mm]	3.175			Arc Voltage [Volt]	13	12.8	12.7	12.83
Wall [mm]	0.22			Arc Current [Amp]	3.40	3.40	3.40	3.40
Level Distance [°]	**340**	↓		Heat Input [J/mm]	13.29	13.09	12.99	13.12
Speed [RPM]	**20**	=						
Speed [mm/min]	199.49							
Weld time [sec]	2.83							
Standard Tube Type	316L SS			**Weld #**	**4**	**5**	**6**	**Average**
OD [mm]	3.175			Arc Voltage [Volt]	13.5	13.55	13.4	13.48
Wall [mm]	0.22			Arc Current [Amp]	3.30	3.10	3.50	3.30
Level Distance [°]	**560**	=		Heat Input [J/mm]	10.72	10.11	11.28	10.70
Speed [RPM]	**25**	↑						
Speed [mm/min]	249.36							
Weld time [sec]	3.73							
Standard Tube Type	316L SS			**Weld #**	**1**	**2**	**3**	**Average**
OD [mm]	3.175			Arc Voltage [Volt]	13.1	13.3	13.4	13.27
Wall [mm]	0.22			Arc Current [Amp]	3.50	3.20	3.40	3.37
Level Distance [°]	**560**	=		Heat Input [J/mm]	13.79	12.80	13.70	**13.43**
Speed [RPM]	**20**	=						
Speed [mm/min]	199.49							
Weld time [sec]	4.67							

The size of the heat-affected zone depends on the size of the weld being laid, the number of runs used to lay the weld (level distance), the wall thickness of the parent material and the electric current used for welding (see Table).

The grain structure of the weld will be similar to a cast structure in a warm mould with columnar crystals being the main feature.

The HAZ undergoes a degree of recrystallization so the original structure of the parent material is likely to become more equi-axed in nature.

The change in properties depends largely on the grain structure of the parent material.

Poor metallurgical structures may occur in the HAZ depending on the nature of the alloy and cooling rate after welding.

Matallurgy test show that Brittle Martensite was not formed in the HAZ. Therefore the behaviour of the metal in service won't be affected

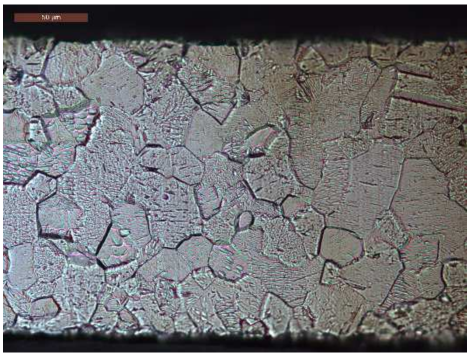


Figure 1. Cross-sectional observations CP2 Ti 3.175 mm OD 0.2 mm wall tube sample. Original magnification: 500 x: Detail of the base material

Conclusion

- Quality of welds
- Only welding system able to do microtube welds.

References

[1] Marquis, G. B., Mikkola, E., Yildirim, H. C. and Barsoum, Z, "Fatigue Strength Improvement of Steel Structures by HFMI: Proposed Fatigue Assessment Guidelines," *Welding in the World*, **57**, Issue 6, (2013) pp 803-822.

[2] R. Scott Funderburk, A look at heat input, Welding Innovation: Key Concepts in welding Engineering, Vol. XVI, No. 1, 1999

[3] R. Leary, et al, Material Science and Engineering A. 527 (2010) 7694-7705