

Orbital Fillet Welding of SS321 Thin Tubes without Electrode Adaptor

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Abstract - Autogenous fillet welding of tube-in-tube of MIL Grade SS321 stainless steel tubes with 4mm to 13mm internal diameter and 6mm to 16mm outer diameter, were joined using Orbitalum® OW 38S weld head and ORBIMAT 180 SW orbital welding machine, without electrode adaptor. Macrostructure and strength of the welded joints were investigated. Fillet welds with smooth contour and good penetration were achieved. The welded joints withstood required pneumatic pressure of 430 ksc and hydraulic pressure of 525 ksc. Welded joints yield strength and tensile strength were between 92% to 100% of the base metal. Percentage of elongation achieved was 58% to 100% of the base metal.

Key Words: Orbital welding, fillet, NDT, stainless steel tube, strength.

1. INTRODUCTION

Welding in the aeronautics industry is experiencing exciting developments. The widespread application of computers and the improved knowledge and design of new materials are shaping the way welding is implemented and process and product are being designed. Welds are replacing rivets in a variety of components in both military and commercial airplanes, to improve both cost and structural integrity. Diffusion, laser, and electron-beam welding are preferred in commercial aircraft, while electron-beam welding is continually gaining ground for the joining of titanium alloys in military airplanes. In large commercial airplanes, laser-beam welds are poised to replace rivets in large parts of the fuselage. Some new processes developed for the space industry also show promise for the aeronautics industry. These include friction stir welding and variable polarity plasma arc welding, which are already being used for critical applications in rockets.

The penetration is measured as the ratio of depth to width of the weld cross section increases dramatically with the intensity of the heat source. This makes the welding process more efficient and allows for higher welding speeds. more efficient process requires less heat input for the same joint, resulting in a stronger weld, as a smaller heat source moving at a faster speed also implies a much-reduced dwell time at any particular point. If the dwell time is too short, the process cannot be manually controlled and must be

automated. The minimum dwell time that can still be controlled manually corresponds to arc welding (approximately 0.3 seconds). Heat sources more intense than arcs have shorter dwell times; therefore, they must be automated.

Orbital welding is a technique whereby the welding tool is rotated through 360° around a static workpiece. Originally developed to solve the problem of operator error in Tungsten Inert Gas (TIG) welding [2,5], and allow for a uniform weld around pipes and tubes, which can be difficult to achieve with manual welding processes. The orbital welding process can create high quality repeatable welds with the use of a computer, meaning that there is little need for intervention from a welding operator. The process is used for two main applications; tube-to-tube / pipe-to-pipe joining and tube-to-tube sheet joining, with pulsed current [3].

MIL Grade SS321 type tubes of different diameters and thickness are used for the manifold preparation required for defence applications. Only square butt weld joints are designed without beveling for the similar diameter tubes, keeping design criteria in view. For dissimilar diameter joints, threaded type lock-tight joints are designed. Tungsten electrode is fixed to the adaptor to weld orbital fillet joints. In this current study, dissimilar tube diameters, ID of bigger tube matching with OD of smaller tube are taken up to weld by orbital TIG welding process, without the adaptor and to evaluate the joint strength and its integrity. The combination of tubes is 4/6 mm (ID/OD), 6/8 mm, 8/10 mm, 10/12 mm, 9/12 mm and 13/16 mm. The critical parameters were optimized [6,7] by trial and error method, and welding was performed in 5G position, maintaining an overlap of 1mm, 2mm and 3mm, respectively in each type of ID/OD combination. To qualify the weld joint, radiographic inspection, macrostructure, hydraulic proof pressure testing, pneumatic proof pressure testing, and tensile properties [4] were evaluated and reported.

2. EXPERIMENTAL PLAN

2.1 Parent Material

The parent material is MIL Grade SS321 tubes of different ID/OD. Tubes, each 150 mm in length were cut using special

diamond cutting wheel from MIL standard tube of 4-meter length. After cutting one face of each sample was treated with a burr removal tool. For tubes 4/6 mm, 6/8 mm, and 8/10 mm, up to a length of 4 mm, buffing was done for the top surfaces to accommodate insertion into the other part of the respective joint tubes. The samples are then cleaned thoroughly in acetone and preserved in desiccators for welding purpose. The nominal composition of the SS321 tube material (wt%) is Fe-17-19Cr, 9-12Ni, 2Mn, 0.7Si, 0.045P, 0.03S, 0.1N, 0.7Ti, and 0.08C.

2.2 Orbital Welding Equipment

The main parts of an orbital welding system are the power supply, ORBIMAT 180 SW (including an integrated computer control), the welding head OW 38S. Tungsten electrode of 1.6 mm diameter is used for welding. Typical joint set-up and welding set-up are shown in the Figure-1 and Figure-2, respectively, below.

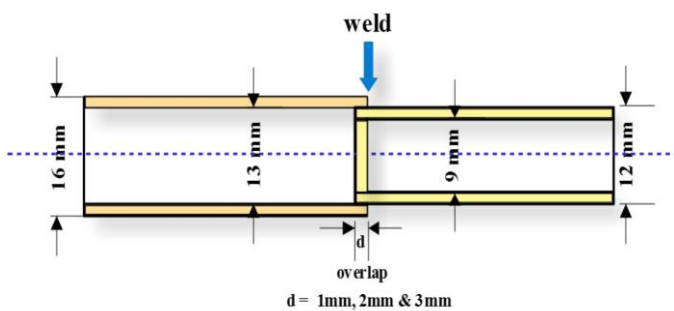


Fig-1: Typical weld joint set-up

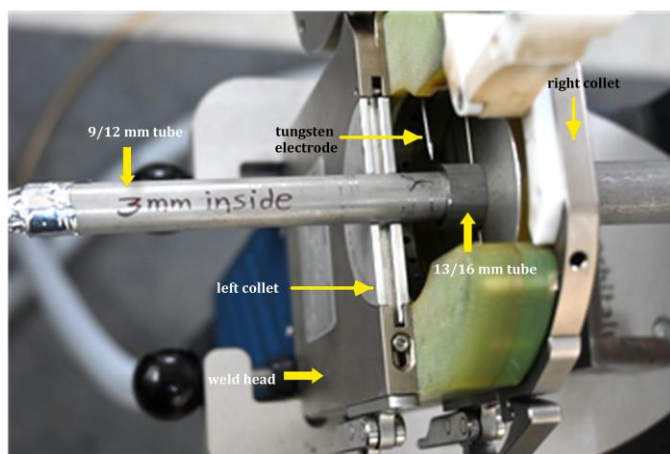


Fig-2: Typical welding set-up for 9/12 mm # 13/16 mm tube joint

2.3 Welding Parameters

The welding was performed with optimized parameters of LP current between 13-16 A, HP current between 35-58 A, and travel speed (TS), between 70-80 mm min⁻¹.

2.3 Radiography

All the welded joints were sent for X-Ray radiographic examination for evaluation of the soundness of the joints. The X-Ray inspection was conducted using Comet 160kV source and DURR HD CR 35 lead plate image scanner and recorded.

2.4 Macrostructure Examination

One sample from each joint configuration was cut using high speed diamond wheel with proper cooling, cleaned thoroughly in acetone, dried and observed for the inside weld features and reported.

2.5 Hydraulic and Pneumatic Leak Testing

In order to evaluate the leak tightness of the welded joints, high pressure pneumatic test at 430 ksc for 5 minutes and hydraulic leak test at 525 ksc for 3 minutes were carried out for all the welded joints.

2.6 Tensile Testing

Three samples of the welded joints were tested using 300kN Universal Tensile Testing machine to evaluate the yield strength, ultimate tensile strength and percent of elongation. Figure-3 shows the tensile test sample configuration as per AWS Sec IX.

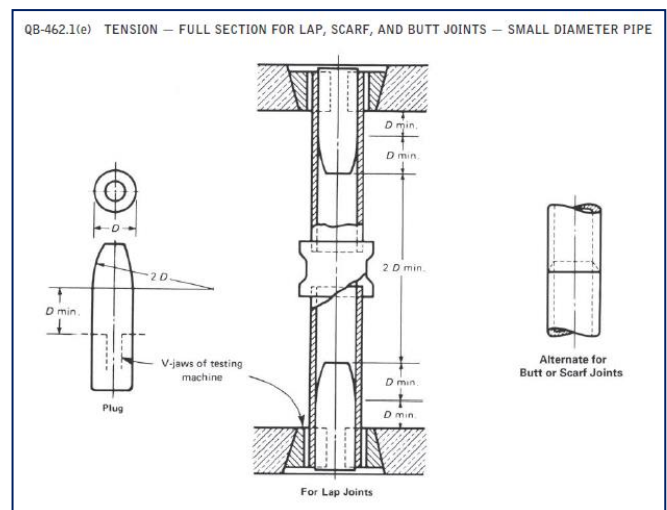


Fig-3: Tensile test sample configuration as per AWS Sec IX [8]

2.7 Fractography

After mechanical testing, the failed samples were examined for fractography and recorded the failure surfaces under low magnification.

3. RESULTS AND DISCUSSION

Figure-4 shows the welded samples with 1 mm, 2 mm and 3 mm overlap, for the joint configuration of 4/6 mm, 6/8 mm, and 8/10 mm. Visual observation of the joint shows smooth bead convex surface profile with excellent coalescence. Figure-5 shows the cut sections of all weld configurations for 1mm overlap. Figure-6 shows the cut sections of the welded joints for the 9/12 mm # 13/16 mm tube joint configuration. The average length of the fusion overlap, as shown by double-headed arrow in Figure-6, measured is 4.18 mm for 1 mm overlap, 3.68 mm for 2 mm overlap and 3.63 mm for 3 mm overlap. But this effect may be ignored as the measurement was made on two cut-surfaces. Also, when we consider the entire length of the circumferential weld, all the overlap length may be within $\pm 10\%$ of variation.

Figure-7 through Figure-10, shows the radiographic images taken using 160kV X-Ray source. The joints show good penetration without any defects. Left and right side of the images, a 2T hole is seen clearly in the radiograph. It means, any defect of size 0.25mm or greater can be identified from the radiograph. Figure-11 shows the test set up for hydraulic pressure proof testing for evaluation, using DM water. Testing was carried out for all the welded configurations, at 525 ksc for 3 minutes and checked with snoop solution during testing, and found no leaks. Figure-12 shows the test set up for pneumatic pressure proof testing for evaluation. Testing was carried out at 430 ksc for 5 minutes, pressuring with nitrogen gas for the dissimilar diameter tube joints. During application of pressure, the welded joints were checked with snoop solution, and there is no leak observed from the joints.



Fig-4: Welded samples

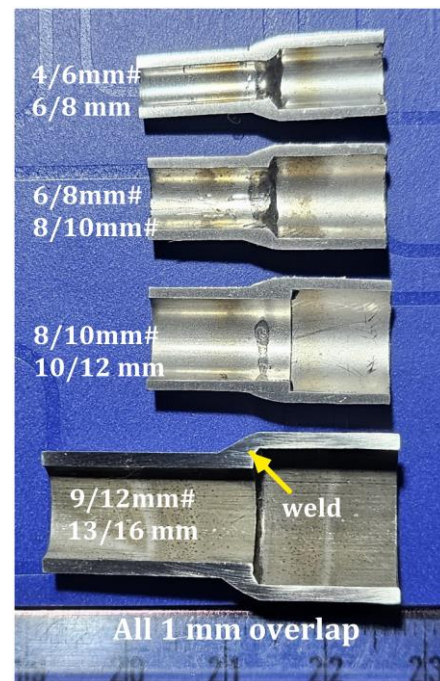


Fig-5: Macro-section of welded samples

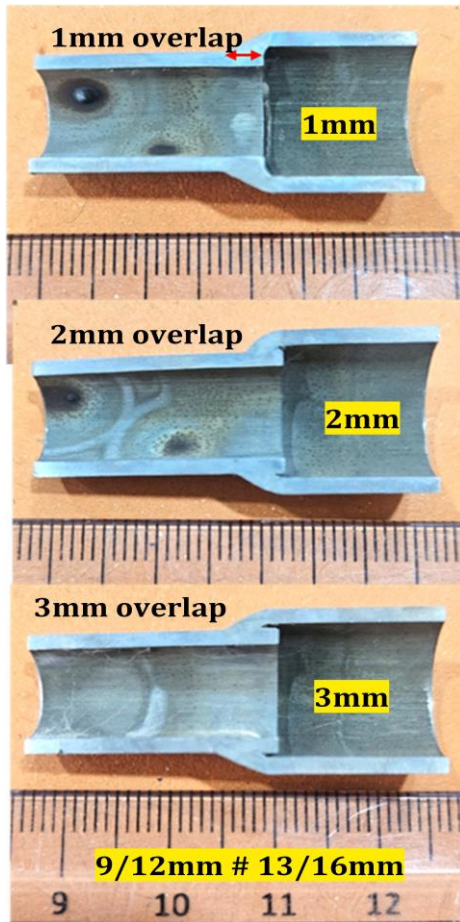


Fig-6: Macro-section of 9/12mm # 13/16 mm welded samples

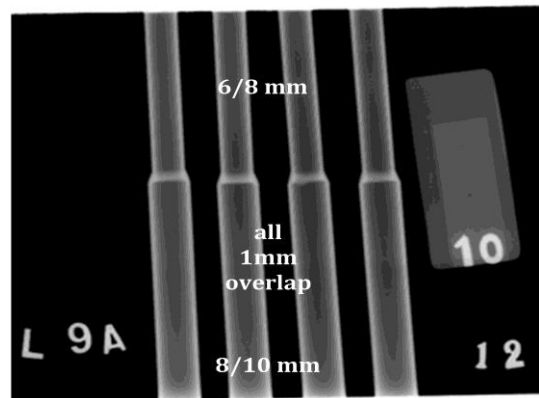


Fig-8: RT Images of 6/8mm # 8/10 mm welded samples

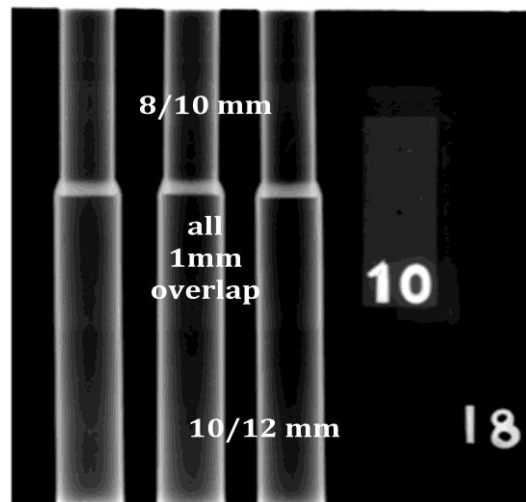


Fig-9: RT Images of 8/10mm # 10/12 mm welded samples

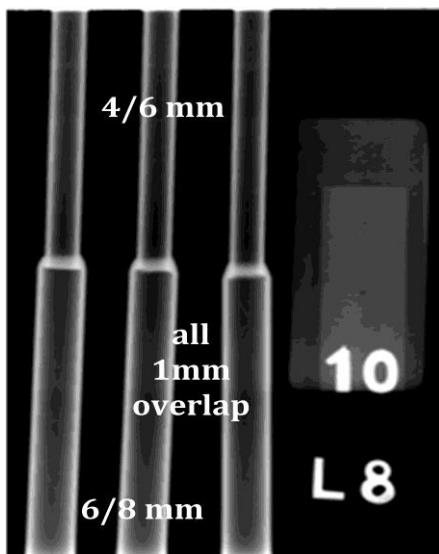


Fig-7: RT Images of 4/6mm # 6/8 mm welded samples

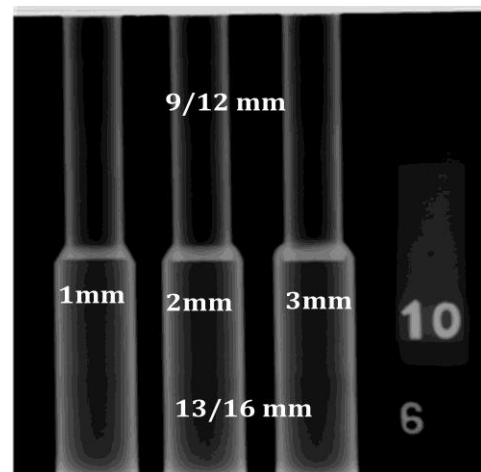


Fig-10: RT Images of 9/12mm # 13/16 mm welded samples

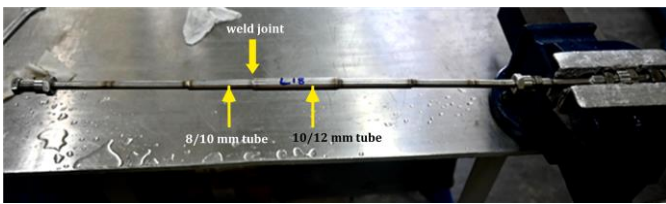


Fig-11: Hydraulic Leak Testing in progress



Fig-12: Pneumatic Leak Testing in progress

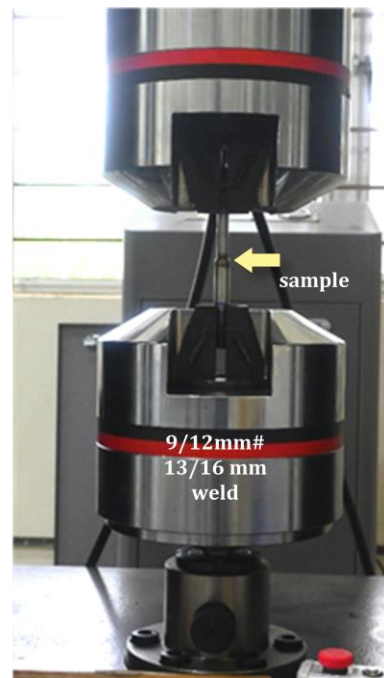


Fig-13: Tensile testing under progress 9/12mm#13/16mm joint

Figure-13 shows tensile testing of 3 mm overlap joint for 9/12mm#13/16mm joint, under progress and Figure-14 shows the completion of testing. In all the three variation of overlap, the failure is observed in the base metal of all the configurations. The fractured samples are shown from Figure-15 through Figure-18. As observed in the cut-section macrostructures in Fig. 4.2 through Fig. 4.4, the mean joint cross section thickness at the weld joint interface is double the wall thickness (3 mm) than that of the individual tube thickness (1.5 mm). Hence the stresses during tensile testing will never reach yield stress during testing at the interface. The failure is always observed in 9/12 mm tube, because the yield stress levels will reach first in 9/12 mm, then in 13/16 mm due to higher cross sectional area of 13/16 mm tube.



Fig-14: Fracture location of 9/12mm#13/16mm joint during tensile testing

Similar behavior is observed in all other weld configurations also. The tensile testing results of other joint

configurations are also shown similar behavior. The failure locations are shown in Figure-15.



Fig-15: Failure location in tensile tested weld joints

Figure-16 through Figure-18, show the tensile plots of welded joints for 6/8mm#8/10mm, 8/10mm#10/12mm, and 9/12mm#13/16mm, respectively. The yield strength and tensile strength are 92 – 100% of base metal. Percentage elongation is 58 – 100% of base metal. The above properties are truly, the scatter in the base metal properties of SS 321 tube, as the failure always occurred in the base material. Hence, it can be claimed that, in the current study, the weld joints have achieved 100% efficiency. The mode of failure is ductile as the percentage of ductility is almost at par with the base metal. The average test results for three sample for each weld configuration and base metal are tabulated in Table-1.

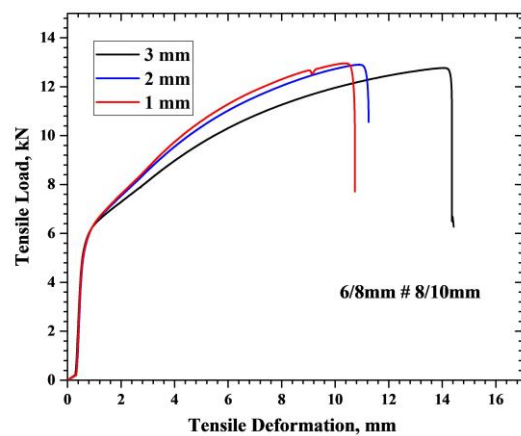


Fig-16: Tensile plots for 6/8mm#8/10mm joints

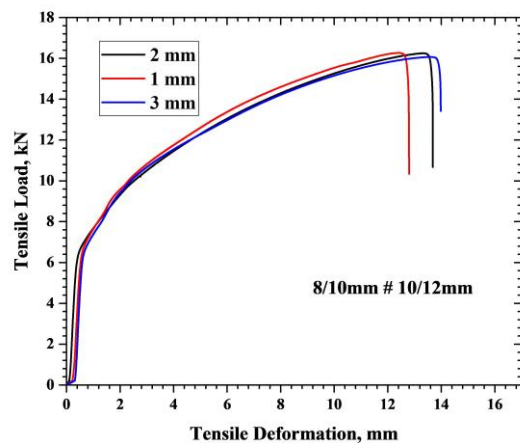


Fig-17: Tensile plots for 8/10mm#10/12mm joints

Table-1: Test Results

Tensile Test Data			
	YS (kN)	UTS (kN)	%Elongation
4/6mm#6/8mm joints	4.14	9.12	29.67
Base metal	4.46	9.86	19.17
6/8mm#8/10mm joints	5.85	12.88	22.83
Base metal	5.77	12.81	36.17
8/10mm#10/12mm joints	7.33	16.20	25.83
Base metal	7.47	16.57	44.17
9/12mm#13/16mm joints	12.73	28.05	45.17
Base metal	13.57	29.75	56

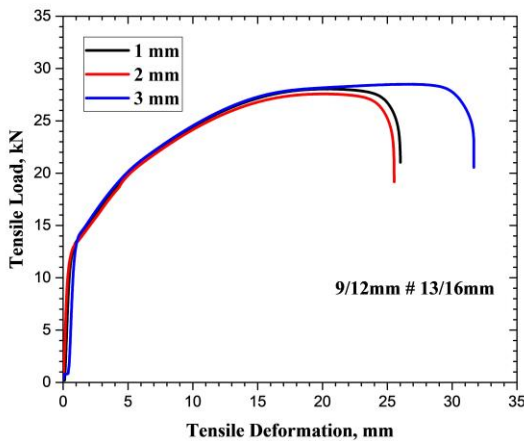


Fig-18: Tensile plots for 9/12mm#13/16mm joints

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BIOGRAPHIES



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