Evaluation Of Mechanical Properties Of Dissimilar Metal Tube Welded Joints Using Inert Gas Welding

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ABSTRACT

Evaluation of welding process such as metal inert gas welding and tungsten inert gas arc welding on tensile, bend and hardness properties of austenitic stainless steel SS347H(18Cr 10Ni 1Cb), T22(2¼Cr Mo) and T91(9Cr 1Mo V) grades are studied. Tubes of 54 mm of outer diameter and 4 mm of wall thickness is used as a base material in the following combination SS347H VS T91 and T91 VS T22 is welded using both GMAW and GTAW. Tensile, impact, and hardness properties of the welded joints have been evaluated in both types of welding and the results are compared. The joints fabricated by GTAW joints exhibited higher strength value and enhancement in strength value is approximately 21% compared to GMAW joints. Very low hardness is recorded in the GMAW joints and maximum hardness is recorded in the GTAW joints. Various defects occurring in the welded joints are analyzed using Non destructive testing by Real time radiography method.

KEYWORDS: SS347H vs SA213T91 and T91 vs T22, GTAW, GMAW, Tensile, Bend test, Radiography

1.0. INTRODUCTION

Welding is a process of joining similar or dissimilar materials. Welding is carried out by the use of heat or pressure or both and with or without added metal. There are many types of welding including Metal Arc, Tungsten arc, Submerged Arc, Resistance Butt, Flash, Spot, Stitch, Stud and Projection. Inert gas welding is faster than traditional welding methods. It can produce cleaner, longer continuous welds. There are two main types of inert gas welding they are Tungsten Inert Gas Welding(TIG) a good description of which is given by by Paulo J Modenesi et al [1] and METAL Inert Gas welding(MIG) by William R. Oates et.al [2]

Alloy Steel referred in MyreRutz [3] such as SA213T91, SA213T22, SA213TP347H contains chromium and molybdenum. This composition delivers good weldability and high hardenability for the above stated alloys. Chromium provides improved oxidation and corrosion resistance. And the molybdenum increases strength at elevated temperature. The combination of chromium and molybdenum also increases resistance to high temperature hydrogen attack and to creep. Chromium and molybdenum steels are used in various products forms according to ASTM specifications by J C Vaillant et.al [4] .

An investigation was carried to study the efficacy of MIG and TIG welding compared using some Mechanical Properties.This paper mainly deals with paper work done by V Balasubramanian et.al [5], J C Vaillant et.al[4] such as Tensile,Bend and Hardness properties by Louis Small [6] .The chemical composition of base metals and filler metal in weight percent is given in Table 1 and 2 respectively.

2.0. MATERIALS AND METHODS

Table 1: Chemical Composition of Base Metal in Accordance with ASTM Standards

	T91	T22	SS347H
C (%)	0.08-0.12	0.05-0.15	0.04-0.10
Mn (%)	0.30-0.60	0.30-0.60	max. 2.00
P (%)	max. 0.020	max. 0.025	max. 0.045
S (%)	max. 0.010	max. 0.025	max. 0.030
Si (%)	0.20-0.50	max. 0.50	max. 1.00
Cr (%)	8.002-9.50	1.902-2.60	17.0-19.00
Mo (%)	0.85-1.05	0.87-1.13	---
V (%)	0.18-0.25	---	---
Nb (%)	0.06-0.10	---	0.80-1.10
N (%)	0.030-0.070	---	---
Al (%)	max. 0.04	---	---
Ni (%)	max. 0.40	---	9.0-13.0
Fe (%)	balance	Balance	balance

The filler metal is the quantity of metal added in the making of the joint and it is in the form of the electrode. The following table entails the chemical composition of the filler material used in GMAW and GTAW:

Table 2: Chemical Composition of Filler Metal

Material	C (%)	Mn (%)	P (%)	Si (%)	Cr (%)	Ni (%)	Mo (%)	Cu (%)	Ti (%)	Nb (%)	Co (%)	Fe (%)
ER90S-B3	0.12	0.7	0.025	0.7	2.7	0.2	1.2	--	--	--	--	Bal
ERNiCr-3	0.02	3.5	0.015	0.15	18-22	67 min	--	0.2	0.6	2	0.05	1.5

Gas Tungsten Arc Welding and Gas Metal Arc Welding are both governed by a set of factors and conditions such as amount of current, welding speed, polarity, etc. which are called as process parameters. The optimum process parameters generally maintained during the welding processes for SS and T22 are given in the Table 3.

Table 3: Welding Conditions and Process Parameters

Parameters	Process			
	GTAW		GMAW	
Joints	T22+ T91	T91+SS347H	T22+T91	T91+SS347H
Polarity	AC	AC	DCRP	DCRP
Arc voltage (V)	22	22	30	30
Welding current (A)	80	80	140	140
Welding speed (ipm)	0.6	0.6	3.2	3.2
Heat input (J/mm)	800	800	1125	1125
Electrode diameter (mm)	0.8	0.8	0.8	0.8
Shielding gas	Argon (99.99 %)	Argon (99.99%)	Argon(95%) and CO2 (5%)	Argon(95%) and CO2 (5%)
Shielding gas flow rate (lt/min)	14	14	14	14

The specimens of T22, T91, and SS need to be mechanically strong, hard, and corrosion resistant and possess properties suitable for welding. The mechanical properties of the test specimens are summarized in Table 4.

Table 4: Mechanical Properties of Test Specimens

Grade	Tensile strength [MPa]	Yield strength [MPa]	Elongation %	Hardness	
				Brinell	Rockwell
T22	415	205	15	163 HBW	85 HRB
T91	585	415	20	190-250 HBW	90 HRB
SS347H	515	205	35	192 HBW	90 HRB

Metal Inert Gas (MIG) Welding: An arc is struck between a consumable electrode and the metal to be welded. The consumable electrode is in the form of continuous filler metal. An inert gas surrounds the arc and shields it from the ambient to prevent oxidation. Carbon steels, low alloy steels, stainless steels, most aluminum alloys. GMAW machine is shown in the fig 1.

Fig 1: GMAW machine

Tungsten Inert Gas (TIG) Welding: An arc is truck between a tungsten electrode (non-consumable) and the metal to be welded. An inert gas shields the arc from the ambient to prevent oxidation. A filler material is optional. Carbon steels, low alloy steels, stainless steels, zinc based copper alloys can be welded using this process. TIG is quite suitable for welding dissimilar materials. The TIG process is a slower process compared to the MIG process, but the quality of weld is cosmetically better. There is no weld spatter, and the quality of welds is higher than MIG welding. It reduces the rejection and rework, so production cost is less compared to MIG welding by William R. Oates et.al [2], Larry Jeffus [7].

3.0. EXPERIMENTAL SETUP:

Tubes of 54 mm of outer diameter and 4 mm of wall thickness is used as a base material in the following combination SS347H VS T91 and T91 VS T22 is welded using both GMAW and GTAW. Tensile, bending, and hardness properties by Louis Small [8] of the welded joints have been evaluated in both types of welding and the results are compared. Test specimen of GMAW welded joints and GTAW are shown in the Fig 2 and Fig 3.

Fig 2: T91 + SS347H (GMAW & GTAW)

Fig 3: T91 + T22 (GMAW & GTAW)

GMAW was done using a constant current DCRP power source, a metal wire electrode, 0.6-1.6 mm in diameter. The shielding gas used was Argon and carbon dioxide mixture and the GMAW gun and cable assembly was designed to deliver the shielding gas and the electrode to the arc. GTAW was done using AC power source, Tungsten wire as the electrode(non consumable) and Argon as shielding gas.

After the welding process was completed and the joints cleaned, the welded samples were subjected to mechanical testing in order to find out the strength of the joint and evaluate the mechanical properties of the welded joints. The tests that were conducted are summarized as:

Tensile Test: This test was carried out in the Ultimate Testing Machine (UTM). The UTM consists of a load frame for providing support to the machine, a load cell which is a force transducer for measuring the load required, a movable cross head for deforming the specimen. It an extensometer for measuring the extension or deformation. There are output devices for measuring the load which may be in the form of charts or digital displays, in this case, a dial indicator. The tensile specimen shown in Fig 4. The schematic diagram of UTM is shown in Fig 5.

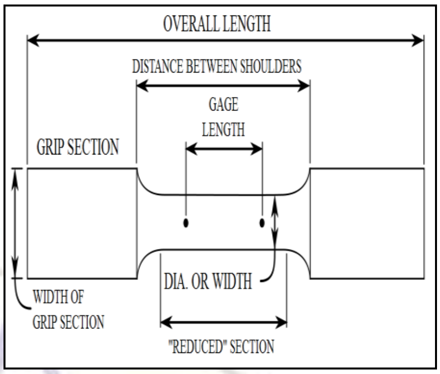

Fig 4: Test specimen

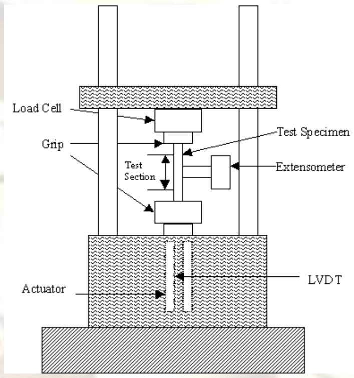

Fig 5: Universal Tensile Testing Machine

The gauge length is that length which is under study. The specimen is placed in the machine between the grips and an extensometer can record the changes in the gauge length during the test. Once the machine is started, it begins to apply an increasing load on the specimen until fracture or failure of the specimen. The yield point indicates the transition point between elasticity and plasticity regions. The ultimate point or stress indicates the maximum stress that the specimen can withstand before failure. The fracture stress or point of rupture is the stress when the specimen fails or breaks. A ductile component fails at 45 degrees.

Vicker's Hardness Test: It is used to measure the wear resistance of the specimen. The machine consists of a diamond indenter in the form of a square pyramid or tetrahedral shape. The impression produced by the indentation under a constant load on the material is measured and more the dimensions of the impression, lesser is the hardness. Its shown in Fig 6. The HV number is determined by the ratio F/A where F is the force applied to the diamond in kilograms and A is the surface area of the resulting indentation in square millimeters.

$A = d^2/2\sin(136/2)$

$HV = F/A$

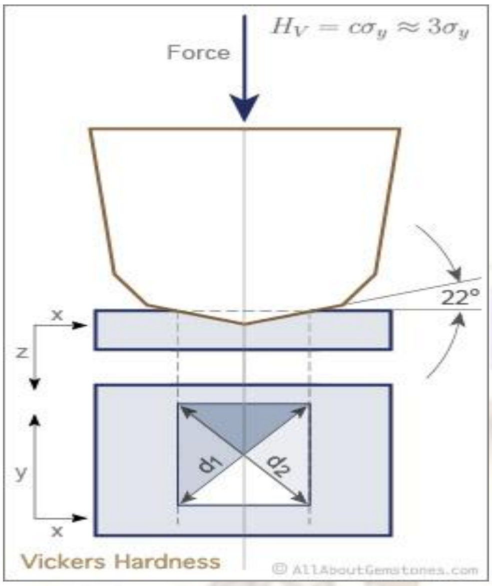

Figure 6: Vicker's Hardness test

Bend Test: This test determines the ductility or strength of the material by bending the material over a given radius. Following the bend, the material is inspected for cracks on the outer surface. Bend test provides insight into the modulus of elasticity and the bending strength of the material. Specimens are often cut into rectangular bars or tested as whole. The bend test is shown in Fig 7.

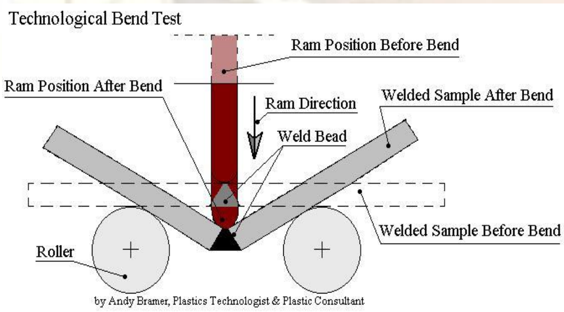

Figure 7: Bend test

Real Time Radioscopy Test: It is a Non Destructive Testing (NDT) method whereby an image is produced electronically rather than on film so that very little lag time occurs between the item being exposed to radiation and the resulting image. In most instances, the electronic image that is viewed results from the radiation passing through the object being inspected and interacting with a screen of material that fluoresces or gives off light when the interaction occurs. The fluorescent elements of the screen form the image much as the grains of silver form the image in film radiography. The image formed is a positive image since brighter areas on the image ondicate where higher levels of transmitted radiation reached the screen. The apparatus is shown in Fig 8.

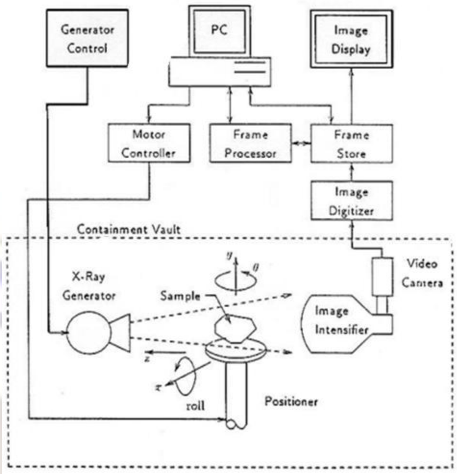

Figure 8: RTR apparatus

4.0. RESULTS AND DISCUSSION:

4.1. Destructive tests:

Destructive weld testing, as the name suggests, involves the physical destruction of the completed weld in order to evaluate its characteristics. This method of testing is used frequently for a number of applications. Some of these applications include welding procedure qualification and welder performance qualification testing, sampling inspection of production welds, research inspection, and failure analysis work. The following results are used to evaluate the tensile strength, hardness and bend properties of welded joints.

4.1.1 Tensile properties:

The transverse tensile properties of GTAW and GMAW welded joints were evaluated in each condition, two specimens were tested and the averages of two results are presented in the Table 5 & 6 respectively. Of the two welded joints, the joints fabricated by GTAW process exhibited higher strength values and the enhancement in strength values is approximately 21% compared to GMAW joints.

Figure 9: Tensile test specimen (GTAW)

Figure 10: Tensile test specimen (GMAW)

Table 5: Tensile Properties of GTAW Process:

T22+T91		
ULTIMATE TENSILE LOAD (KN)	ULTIMATE TENSILE STRENGTH (N/mm²)	FRACTURE
32.79	661	Parent material (T22)
32.25	650	Parent material (T22)
T91+SS347H		
ULTIMATE TENSILE LOAD (KN)	ULTIMATE TENSILE STRENGTH (N/mm²)	FRACTURE
30.22	609	Parent material (SS)
31.48	634	Parent material (SS)

The Table given below shows the ultimate load, stress value and the point of occurrence of fracture of the welded samples:

Table 6: Tensile Properties of GMAW Process

T22+T91		
ULTIMATE TENSILE LOAD (KN)	ULTIMATE TENSILE STRENGTH (N/mm²)	FRACTURE
26.1	549	Parent material (T22)
27.5	576	Parent material (T22)
T91+SS347H		
ULTIMATE TENSILE LOAD (KN)	ULTIMATE TENSILE STRENGTH (N/mm²)	FRACTURE
29.1	586	Parent material (SS)
28.71	579	Parent material (SS)

4.1.2. Hardness Test

The hardness across the weld cross section was measured using a Vickers Micro-hardness testing machine, and the results are presented in Table 7 & 8. The hardness of the Heat Affected Zone (HAZ) region is greater than the weld region and the base metal region. The hardness of the GTAW & GMAW joints in the weld metal region is 270 VHN & 245 VHN respectively for T22+T91 combination. However ,the hardness of T91+SS in GTAW&GMAW joints in weld region is 293 VHN & 197 VHN respectively in both combinations GTAW joints has relatively higher hardness value compared to GMAW joints.

The table 7 below illustrates the hardness values at the parent materials and heat affected zones in units of Vicker's Hardness Number(VHN) for Metal Inert gas Welding:

Table 7: GMAW Process

T22+T91			
	PARENT MATERIAL (VHN)	WELD (VHN)	HEAT AFFECTED ZONE (VHN)
T22	139, 138	240, 245	172, 178
T91	213, 221		251, 268
T91+SS			
	PARENT MATERIAL (VHN)	WELD (VHN)	HEAT AFFECTED ZONE (VHN)
SS347H	165,170	190,197	236,280
T91	183,187		297,297

The Table 8 given below shows the hardness at the weld region, Heat Affected Zone, and Parent metal in terms of Vicker's Hardness Number for Tungsten Inert Gas welding:

Table 8: GTAW Process

T22+T91			
	PARENT MATERIAL (VHN)	WELD (VHN)	HEAT AFFECTED ZONE (VHN)
T22	193, 195	264, 270	230, 236
T91	206,213		308, 325
T91+SS			
	PARENT MATERIAL (VHN)	WELD (VHN)	HEAT AFFECTED ZONE (VHN)
SS347H	185,187	290,293	236, 289
T91	214,220		309, 314

4.1.3. Bend Test:

Bend tests are generally used in the weld qualification process for new fabrication. Similar tests, however, could be conducted for existing structures if original fabrication practices can be simulated. The Guided bend tests are used to evaluate the ductility and soundness of welded joint sand to detect incomplete fusion, cracking, delaminating effect of bead configuration, and macro defects of welded joints. The quality of welds can be evaluated as a function of ductility to resist cracking during bending.

When the plate thickness is less than or equal to 10 mm (3/8 in.), two specimens are tested for face bend and two specimens are tested for root bend. The specimen has been bended to 180° for bending test. The tested specimen is shown in the Fig 11 and 12.

During the test, the convex surface of the bent specimen should be examined frequently for cracks or other open defects. If a crack or open defect is present after bending, exceeding a specified size measured in any direction, the specimen is considered to be failed. Cracks occurring on the corners of the specimen during testing are not considered to fail. The following are the results obtained from the bend test shown in Table 9.

Table 9: Results of Bend Test

GTAW PROCESS		
JOINTS	ANGLE OF BENDING	REPORT
T22+T91	180°	NO BREAKAGE
T91+SS47H	180°	NO BREAKAGE
GMAW PROCESS		
JOINTS	ANGLE OF BENDING	REPORT
T22+T91	180°	NO BREAKAGE
T91+SS347H	180°	NO BREAKAGE

Figure 11: Bend test specimen (GTAW)

Figure 12: Bend test specimen (GMAW)

4.1.4 Non-Destructive Test:

Real-time radiography is a well-established method of NDT having applications in automotive, aerospace, pressure vessel, electronic industries, among others. The use of RTR is increasing due to a reduction in the cost of the equipment and resolution of issues such as the protecting and storing digital images.

The RTR showed various defects in the weld such as the following:

1. Burn Thorough: Shown in Fig 13. Caused due to bent tube ends, slow rotation of D-head, Short wire stick out, high welding current.
2. Wire stub: Shown in Fig 14. Caused due to high wire feed, high current in root pass, improper fit up to joint.
3. Gas hole or Porosity: Shown in Fig 15. Caused due to excessive hydrogen or oxygen in welding atmosphere, high solidification, dirty base metal, dirty filler wire, improper arc length.
4. Undercut: Shown in Fig 16. Caused due to high travel speed, high welding voltage, longer arcs, electrode inclinations, high dwell time.
5. Excessive Penetration: Shown in Fig 17. Caused due to improper alignment of tubes

due to gap in root of weld joint, bent tubes, high welding current.

6. Lack of Fusion: Shown in Fig 18. Caused due to insufficient heat input, wrong type or size of filler wire, incorrect wire position, slag on weld, low travel speed of head, wide torch oscillation.

Figure 13: Burn through

Figure 14: Wire stub

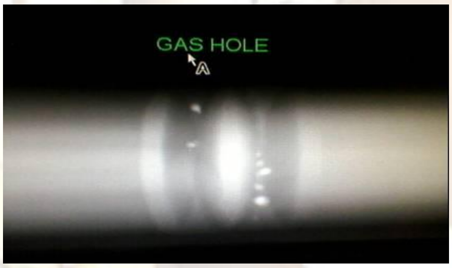

Figure 15: Gas Hole

Figure 16: Undercut

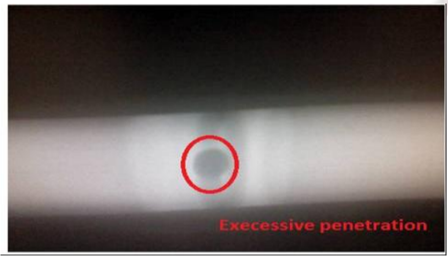

Figure 17: Excessive penetration

Figure 18: Lack of fusion

Transverse tensile properties of the welded joints presented in the table indicate the GTAW joints exhibiting suprior tensile properties. During tensile test, all the specimens failed at the base metal of welding processes. This implies that the Heat Affected Zone (HAZ) region is much stronger than the base metal. This also evident from the hardness profile in shown in table.

In GTAW, the alternating current (AC) polarity ia used, and the high heat generation end is continuously changing. Whenever, the eletrode becomes positive, more heat is generated (2/3 of total heat) at this end. Similary, whenever the work piece becomes positive, more heat is generated at this end. In one half of a cycle, eletrode attains maximum heat and in the other half of a cucle, work piece attains minimum heat, and this will change in the next cycle. So, while using AC , the maximum heat generating end is not fixed as in the case of GMAW process. Whatever, it may be the process, the heat energy from the arc is utilized to melt the filler metal as well as to melt the base metal. However in GTAW, the filler rod is melted in the plasma region of the arc (midway between positive & negative polarity) and not in the positive polarityu as in the case of GMAW processes. Due to the reason, heat input of GTAW process is lower than for GMAW process. Lower heat input and lower current density reduces the arc temperature and arc forces in GTAW. Lower arc temperature reduces the peak temperature of the molten weld pool and adjacent HAZ causing a fast cooling rate. This fast cooling rate in turns , causes relativelt narrower dendric spacing in the fusion zone. This may be one of the reasons for higher hardness and superior tensile properties of GTAW joints compared to GMAW joints.

Figure 16: Undercut

5.0. CONCLUSIONS

Two combinations of materials namely T91+T22 and T91+SS have been welded using both GTAW and GMAW process. Welding has been done on six specimen of each combination. Tensile, Hardness, Bend, NDT (Real time radigraphy) tests have been performed and the following conclusions have been done.

Of the two welded joints, the joints fabricated by GTAW process exhibited higher strength value and enhancement in strength value is approximately 21% compared to GMAW joints.

The strength and hardness value has been increased due to precipitation of chromium carbide and tungsten carbide. And due to the combined effect of wok hardenability.

Hardness is higher in the HAZ region compared to the weld metal and base metal region. Very low hardness is recorded in the GMAW joints (190 VHN) and the maximum hardness is recorded in the GTAW joints (293 VHN).

The Real Time Radioscopy (RTR) showed the defects occurring in the weld such as burn through, wire stub, gas holes or porosity, undercut, penetration, cracks and their remedies have been discussed as follows:

1. Burn Through: Can be remedied by making the ID bore concentric with the OD bore, perfect tube ends, ensuring slow rotation of D-heads, supplying perfect welding current.
2. Wire stub: Remedied by proper selection of wire feed, suitable selection of current, making proper alignment of tubes in root of weld joint.
3. Porosity: Remedied by using low hydrogen welding process, increasing shielding gas flow, increasing heat input, using clean joint faces, using electrodes with basic slugging reactions.
4. Undercut: Rectified by ensuring lower travel speeds, correct welding voltage, clean weld surfaces, ensuring correct dwell times.
5. Excessive penetration: Can be rectified by proper alignment of tubes in root of weld joint, concentric bore at ends, correct welding current, controlling the rotation of D-head.
6. Lack of Fusion: Remedied by choosing correct size of electrode, correct position of electrode, ensuring that weld metal does not run ahead of arc, clean weld surfaces, narrow torch oscillations.

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