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Research Article

Comparative Evaluation of Mechanical Properties and Micro Structural Characteristics of 304 Stainless Steel Weldments in TIG and SMAW Welding Processes

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Abstract

Welding technique is one of the widely used permanent fastener techniques, where in different types of welding are used for different applications. Welding creates property changes in the welded location, so it is important to investigate the core mechanical properties after welding to create better designs using welding techniques. In this project the effect of the welding process of Shielded Metal Arc Welding (SMAW) and the relatively Tungsten inert gas welding (TIG) process on 304 Austenitic Stainless steel is studied. The welding process was carried out on 6mm thick plate of 304 Stainless Steel using SMAW and TIG welding processes The two set of plates having the single plate size of 200mmX150mmX6mm were welded using Tungsten Inert Gas welding And Shielded metal arc welding process. This project focuses on tensile property, toughness; micro hardness and micro structure of the each welding process of weld joints are studied and compared with those properties of each process related to the base metal, which shows the better welding process on Stainless Steel. The output variables of SMAW and TIG welding process on 6mm weld plate tensile strengths are compared. The studies indicated that the TIG joints were having better tensile strength than SMAW welded joints on 304stainless steel.

Keywords: *Shielded Metal Arc Welding (SMAW), Tungsten Inert Gas Welding (TIG), Stainless Steel 304, ASTM Tensile Testing*

1. Introduction

Welding is a joining process of similar metals but nowadays it is also joining dissimilar metals by the application of heat. Welding can be done with or without the application of pressure. It is can be done addition of filler materials or without addition of filler materials. While welding the edges of metal pieces either melted or brought to plastic condition and it is used for permanent joints. The joint gets stronger when it cools down. It's heats when the weld pool is used with the workpiece and produces weld in that time. In all fabrication companies welding is very essential (Karalis, 2009). Since welding has been used in steel fabrication its uses has expanded in other industrial sectors like construction, mechanical and car manufacturing etc.

If look back in the past, can see that welding had been used for many years. It has been passed through the Bronze age and the Iron age and it has branched around the world. Ever since 17th century, after the industrial revolution, technology has made our lives comfortable. Man started using iron and steel and since then they play a crucial role in our day to day lives (Lothongkum, 2001). There are simply surrounded by metals. Thus it has aided in almost all sectors of our lives. It in the most places, the things are doing or use to accomplish our work. One of the strongest methods of joining any metal is through fusion with the help of Arc welding. Technically speaking, electric current allows the electric arc to melt 2 metal pieces, a filter material is used which enables the pieces to mix and as it cools it solidifies into one piece.

Although in its present form it has been used beginning of 20^{th} century but it fast replacing other joining process like riveting and bolting (Durgutlu 2004). Presently welding is used extensively for fabrication of different components in automobile bodies, bridges, aircraft frames, chemical plants, nuclear reactors, structural's and earth moving equipments, railway wagons, pipe and tube fabrication, ship building, general repair works, etc.,.

Welding often an industrial process it may be used for different environments, including open air under water and in outer space. Many different energy sources can be used for welding, including gas flame, electric arc, laser, electron beam, friction, and ultra sound. This is related with soldering and brazing, which involve melting a lower melting point material between the workpieces to from a bond between them, without melting the workpieces. Welding is a most careful and precautions are required to avoid burns, part damages, electric shocks, protect from

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poisonous gases and fumes, and exposure to ultraviolet radiation.

Although, almost all materials (metals, plastics, ceramics, and composites) can be welded but not by the same process, to achieve the universality a large number of welding and related process have been developed. Most of industrial important processes are classified depending upon the nature of heat source and its movement resulting in spot, seam welds or on the low heat or high heat (Wang, 2011). Today developments continues to advance of robot welding is common place in industrial setting, and researchers continue to develop new welding methods and gain greater understanding of weld quality. The Most of welding work reviewed in aims at predicting or analyzing the structural response of the welded structure, focusing mainly on the residual stresses and deformations.

1.1 Shielded metal arc welding

This is a simply called as arc welding. It is one of the methods of fusion welding process of joining two metal pieces by melting their edges by an electric arc between two conductors. The electrode is one conductor and the work piece is another conductor. The electrode and work piece are brought nearer with a small air gap, the gap should maintaining nearer 3mm approximately. This process employs coated or covered electrodes for producing an arc to act as a heat source, the covering on burning provides the necessary shield to protect the molten metal from the effect of oxygen and hydrogen from the surrounding atmosphere (Woo-Gon Kim, 2013). This process popularly known as stick electrode welding or manual metal arc welding and is the single most used welding process in the world.

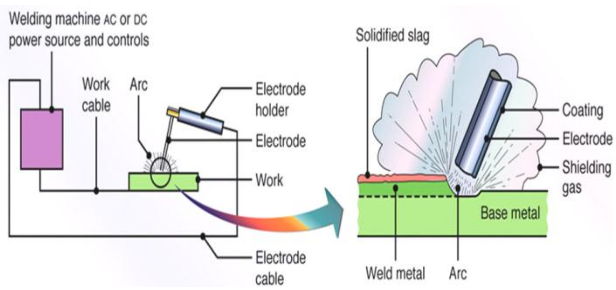


Fig-1.1 SMAW Welding (Serope Kalpakjian, 2006)

Both AC and DC power can be used equally effectively. Fig 1.1 shows the SMAW circuit diagram for the process. When current is passed, an electric arc is produced between the electrode and the work piece. The electrode and work piece is melted by the arc. The weld pool is produced depends on the size of the covered electrode and the welding current used and may vary from very small to fairy large sizes. About 70% of the heat liberated due to striking of electrons at anode raises the anode temperature to very high values. This heat melts the base metal as well as tip of the electrode in the area surrounding the arc. A weld is formed when the mixture of molten base and electrode metal solidifies in the weld area. Since 70% heat is generated at anode a work piece connected to anode will melt 50% faster as compared to if connected with cathode. This is why work piece is usually made positive and electrode as negative and is termed as straight polarity.

1.2 Tungsten inert gas welding

TIG welding is an abbreviation for **Tungsten Inert Gas Welding.** TIG welding is an electric arc welding process in which the fusion energy is produced by an electric arc burning between the work piece and the tungsten electrode. If it is necessary to use filler material it is added either manually or automatically as a bare wire. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas (Q.Wang, 2011). By means of a gas nozzle the shielding gas is lead to the welding zone where it replaces the atmospheric air.

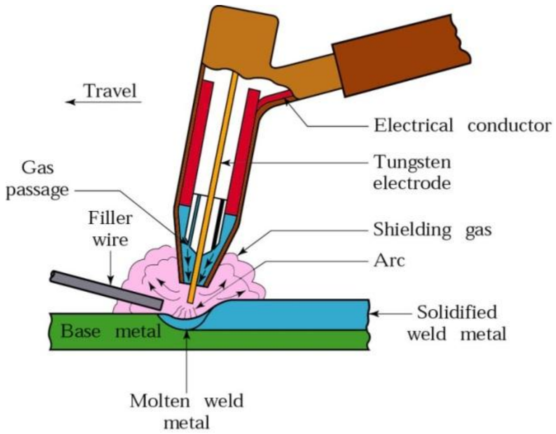


Fig-1.2 TIG Welding Process (Serope Kalpakjian, 2006)

TIG welding differs from the other arc welding processes by the fact that the electrode is not consumed like the electrodes in other processes such as MIG/MAG. In this welding an electric arc is produced between a non-consumable tungsten electrode and the work piece.

There is an electrode holder in which the non-consumable tungsten electrode is fixed. When the arc is produced between the electrode and work, the inert gas from the cylinder passes through the welding head around the electrode. The inert gas surrounds the arc and protects the weld from atmospheric effect, so weld are made without defects. The process is used for welding steels, aluminum, cast iron, magnesium, stainless steel etc.,. The inert gas used in this process for protection is Argon or Helium. It has made survival much simpler than what it was few centuries ago and made life more simpler allowing man to be more intellectual and creative to make at most use of it. There are many different kinds of welding. TIG welding is one among them. There certain requirements and procedures that ought to be followed in order to practice TIG welding and perfect it.

1.3 Stainless steel

The selected material was Stainless steel 304 grade. When austenitic stainless steel joints are employed in cryogenic and corrosive environment the quantity of ferrite in the welds must be minimized or controlled to avoid property degradation during service. Iron and the most common iron alloy, steel, are from a corrosion viewpoint relatively poor materials since they rust in air, corrode in acids and scale in furnace atmospheres. In spite of this there is a group of iron-base alloys, the iron-chromium-nickel alloys known as *stainless steels*, which do not rust in sea water, are resistant to concentrated acids and which do not scale at temperatures up to 1100°C (Sharifitabar, 2011). It is this largely unique universal usefulness, in combination with good mechanical properties and manufacturing characteristics, which gives the stainless steels their raison and makes them an indispensable tool for the designer.

The usage of stainless steel is small compared with that of carbon steels but exhibits a steady growth, in contrast to the constructional steels. Stainless steels as a group is perhaps more heterogeneous than the constructional steels, and their properties are in many cases relatively unfamiliar to the designer. In some ways stainless steels are an unexplored world but to take advantage of these materials will require an increased The materials employed are location dependent in the same structure for effective and economical utilization of the special properties of each material (Andrés R. Galvis, 2011). Only in this way can the designer use most suitable materials for each part of a given structure.

1.4 Tensile testing

Tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and Young's modulus. These important parameters obtained from the standard tensile testing are useful for the selection of engineering materials for any applications required. The tensile testing is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) till failure. The applied tensile load and extension are recorded during the test for the calculation of stress and strain.

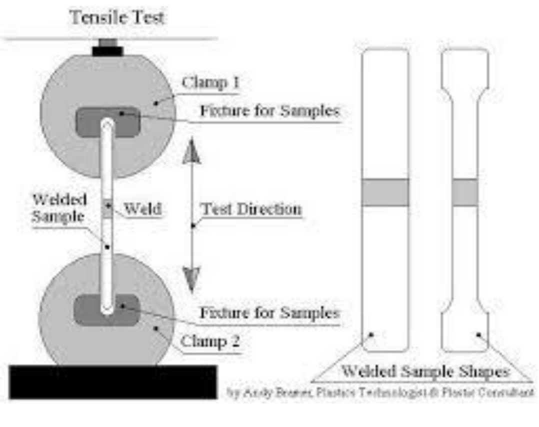


Fig-1.3 Tensile Testing

For instance, ASTM standard test method for tension testing of metallic materials and ASTM B557 is standard test methods of tension testing wrought and cast aluminium and magnesium alloy products A standard specimen is prepared in a round or a square section along the gauge length depending on the standard used. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing.

The initial gauge length Lo is standardized (in several countries) and varies with the diameter (Do) or the cross-sectional area (Ao) of the specimen as listed in table 1. This is because if the gauge length is too long, the % elongation might be underestimated in this case. There might be some exceptions, for examples, surface hardening or surface coating on the materials. These processes should be employed after specimen machining in order to obtain the tensile properties results which include the actual specimen surface conditions.

Table 1.1 Dimensional relationships of tensile specimens used in different countries.

Type specimen	United State (ASTM)	Great Britain	Germany
Sheet (L_o / $\sqrt{Ao}$)	4.5	5.65	11.3
Rod (Lo / $\sqrt{Do}$)	4.0	5.0	10.0

2. Experimental Methodology

However the steel can able to weld in different welding processes which results having different strength. So the effect of welding on TIG and SMAW welding process on steel is changes its property. The mechanical property of the weldment of Shielded metal arc welding piece and Tungsten inert gas welding piece is to be analyze and it has to shows the strengthened value that closer to parent metal property. To determine the micro hardness values of the weldment of shielded metal arc welding piece and Tungsten inert gas arc welding piece so as to say the better hardness value by compared to Base metal hardness. To analyze micro structure of shielded metal arc welding and tungsten inert gas welding pieces on weldment and base metal so as to shows the micro structural effect of welding.

Table 2.1 Chemical Composition of Base Metal (wt.%)

Composition	C	Si	Mn	Cr	S	P	Ni
AISI SS 304	0.06	0.32	1.38	18.4	0.28	0.4	8.17

There are 4 stainless steel plates having the length and width 200mmX150mm and 6mm thick plate. Two plates are joined by SMAW simply called as arc welding by SMAW welding of plates. With having the 45^0 angle of each plate forming V-groove at 0.5mm bottom thick for welding. The process can use butt welding of joining process. The electrode and work piece are brought nearer with a small air gap, the gap should maintaining nearer 3mm approximately. Both AC and DC power can be used equally effectively. The SMAW circuit diagram for the process. When current is passed, an electric arc is produced between the electrode and the work piece. The electrode and work piece is melted by the arc.

Table 2.2 Chemical Composition of Electrode metal (wt.%))

Composition	C	Si	Mn	Cr	S	P	Ni
SS E308L	0.01	0.40	1.6	20	0.20	0.4	10

In TIG Welding There are 2 stainless steel plates having the length and width 200mmX150mm and 6mm thick plate. Two plates are joined by TIG welding process. With having the 45^0 angle of each plate forming V-groove at 0.5mm bottom TIG welding is an abbreviation for Tungsten Inert Gas Welding. TIG welding is an electric arc welding process in which the fusion energy is produced by an electric arc burning between the work piece and the tungsten electrode. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas. By means of a gas nozzle the shielding gas is lead to the welding zone where it replaces the atmospheric air

2.1 Welding parameters

The process parameters for two different welding process are same for example welding current, arc voltage etc., because of inspection two process of different welding have same parameter and electrode and base metal. The electrode selected for the Shielded metal arc welding is E308L stainless steel material because of 304stainless steel. The electrode have to prepare slightly high grade for welding. For welding the two different same grade may be not suitable for same grade material so select slightly more grade electrode.

Table 2.3 The specifications of a typical (A.C) transformer for the welding are given below:

Phase	3phase, 50 cycles/sec
Current	50 A to 400 A
Open circuit voltage	80 volts
Efficiency	0.85%
Power factor	0.4
Energy consumption	4kWh/kg of Metal deposit
Welding speed	1 min/200mm

The SMAW and TIG welding same electrode grade E308L stainless steel used. The welding parameters of each process should same including the electrode, for testing of the welded material with same procedure have to select same material.

3. Results and Discussion

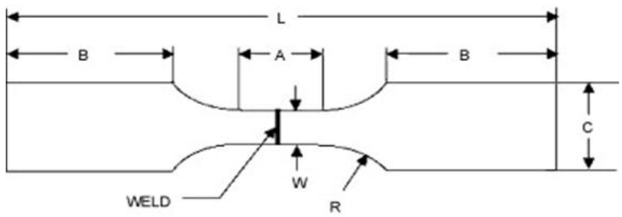
The SMAW process of two plates having 6mm thickness (Fig 3.1.a), When current is passed, an electric arc is produced between the electrode and the work piece. The electrode and work piece is melted by the arc. The weld pool is produced depends on the size of the covered electrode and the welding current used and may vary from very small to fairy large sizes. About 70% of the heat liberated due to striking of electrons at anode raises the anode temperature to very high values. This heat melts the base metal as well as tip of the electrode in the area surrounding the arc.

Fig 3.1 (a) SMAW process (b) TIG process

A weld is formed when the mixture of molten base and electrode metal solidifies in the weld area. Since 70% heat is generated at anode a work piece connected to anode will melt 50% faster as compared to if connected with cathode. This is why work piece is usually made positive and electrode as negative and is termed as straight polarity.

There is an electrode holder in which the non-consumable tungsten electrode is fixed and the weld plate shown Fig 3.1 (b). When the arc is produced between the electrode and work, the inert gas from the cylinder passes through the welding head around the electrode. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas. By means of a gas nozzle the shielding gas is lead to the welding zone where it replaces the atmospheric air. TIG welding differs from the other arc welding processes by the fact that the electrode is not consumed like the electrodes in other processes such as MIG/MAG and MMA. In this welding an electric arc is produced between a non-consumable tungsten electrode and the work piece. The inert gas surrounds the arc and protects the weld from atmospheric effect, so weld are made without defects.

3.1 Testing



Name	Dimensions (mm)
L	300
A	50
W	20
R	25
B	90
C	35

Fig 3.2 ASTM Testing specimen

The ASTM (American Society for Testing and Materials) standard tensile testing specimen for tensile testing on as per norms of ASTM A 240 on welding work piece. Mainly there are two types of standard dimensions one for plate and another for rod type specimen. Now the profile is used for welding of plate type specimen. So the selection of standard tensile testing specimen is plate type standard specimen for welding.

The applied tensile load and extension are recorded during the test for the calculation of stress and strain. Tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and Young's modulus. The selected test specimen dimensions are shown below Fig 3.2.

The two tensile specimens are prepared for the testing and fixing the average tensile strength of two specimens is the tensile strength of the particular type welding specimen. The tensile test specimen of TIG and SMAW weld piece after cutting and before testing is shown in below fig 3.3 TIG and SMAW Tensile specimen. Then tensile testing conducted on the ASTM Tensile testing machine. The specimen it grooved some small distance for holding the specimen holder of machine. To hold and given the tensile load on it, it will elongate and fracture some after load given to it.

The specimen reaches its ultimate tensile load slightly losses their strength and it is showed on the graph of tensile machine. After the ultimate load suddenly curve propagation goes on opposite direction. Then it will break certain load rate on the load scale it is called as fracture load or strength of the specimen.

(a) TIG and SMAW Specimen (Before testing)

(b) TIG and SMAW Specimen (After testing)

Fig 3.3 TIG and SMAW Testing specimen

The testing results on the Base metal or Parent metal of selected material as per any one ASTM tensile testing standard specimen size. This is facilitating the comparison of testing the material at actual base metal to the welded metal of Austenitic 304 stainless steel.

The selected base metal SS304 cut the specific dimensions as per the ASTM standard specimen. Then it can be tested in tensile testing machine. The testing result of base metal properties is note down and tabulates the values. The tensile properties of base metal are tabulated in the table 3.1 Tested Specimen values of Base metal. The testing of base metal tensile properties are done and the load value of the base metal at yield and ultimate point is the main factor to be compared with the welded material properties. It should be less than the base metal properties because heat affected slightly on the material property of base metal.

So it can be used to compare and evaluate the nearest welding metal property from the base metal. The specimen dimensions of each work plates are nearly same but the process of welding is changes and its goes for the tensile testing.

Table 3.1 Base metal tensile testing results

Tested work piece	Final Specimen Width (mm)	Final Specimen Thickness (mm)	Final Gauge Length (mm)	Final Cross Sectional area (mm)	Yield Load (kN)	Yield Stress (N/mm^2)	Peak Load (kN)	Tensile Strength (N/mm^2)	Reduction in Area (%)	Elongation (%)
	7.7	3.9	78.30	30.03	39.36	504.6	49.22	631.50	61.50	56.60

So it can be used to compare and evaluate the nearest welding metal property from the base metal. The specimen dimensions of each work plates are nearly same but the process of welding is changes and its goes for the tensile testing.

The main specimen dimension of each weld plates are shown in the below table 3.2 Tensile Specimen Dimension. The specimen dimensions of each work plates are nearly same but the process of welding is changes and its goes for the tensile testing. The main specimen dimension of each weld plates are shown in the below table 3.2 Initial Specimen Dimension.

Table 3.2 Initial welded specimen sizes

Specimen data	TIG Specimen 1	TIG Specimen 2	SMAW Specimen 1	SMAW Specimen 2	Base Metal
Specimen width (mm)	19.3	20.3	20.5	19.9	13
Specimen thick (mm)	6	6	6	6	6

Initial gauge length (mm)	50	50	50	50	50
Specimen Cross Section area (mm^2)	115.8	121.8	123.00	119.4	78

The initial stage of the specimen showed result should deviate from the result taken after the tensile testing on it. Because of the specimen at the ultimate load will slightly elongate then it suddenly goes on opposite direction and break it.

Table 3.3 Testing results of welding processes

Tested Specimen data	TIG Specimen1	TIG Specimen2	Average	SMAW Specimen1	SMAW Specimen2	Average
Final Specimen Width (mm)	13.12	13.80	13.46	15.54	14.70	15.12
Final Specimen Thickness (mm)	4.30	4.20	4.25	4.20	4.40	4.30
Final Gauge Length (mm)	73.30	73.60	73.45	70.80	71.00	70.9
Final Cross Sectional area (mm)	56.42	57.96	57.19	65.27	64.68	64.97
Yield Load (kN)	52.45	56.03	54.24	53.38	52.54	52.96
Yield Stress (N/mm^2)	452.94	460.02	456.48	433.98	440.03	437
Peak Load (mm)	67.39	71.25	69.32	69.00	65.91	67.45
Ultimate Tensile Strength at (N/mm^2)	581.95	584.98	583.46	560.98	552.01	556.49
Reduction in Area (%)	51.28	52.41	51.84	46.93	45.83	46.38
Elongation (%)	46.60	47.20	46.90	41.60	42.00	41.8
Welding efficiency (%)	583.46/631.50 = 93.39 %			556.49/631.50 = 88.12 %		

The value of after tensile testing slightly decreases from the initial dimension value on the welded region. The strength value of the welded specimen after the testing is shown in the below table 3.3.Testing results of welding processes.

The tensile tested specimen dimensions and their load values, strength, percentage of elongation, reduction in cross sectional area of the two specimens of each process and their data's are showed in the above table 3.3 tested specimen values The average value of two specimen of each process is calculated and tabulated the values on the same table. Then the average values that shows the SMAW and TIG welding of tensile property of the stainless steel plate results. It plots the difference between tensile property of two welding and their results that nearer to the actual or base metal tensile properties, is the better one from the compared efficiency of welding processes

4. Conclusion

The weld ability properties of, namely tensile strength of the Shielded metal arc welded and welded and Tungsten inert gas welded austenitic 304 stainless steel were studied. And it shows the yield strength and ultimate strength of TIG welding properties were better than the SMAW welding properties.

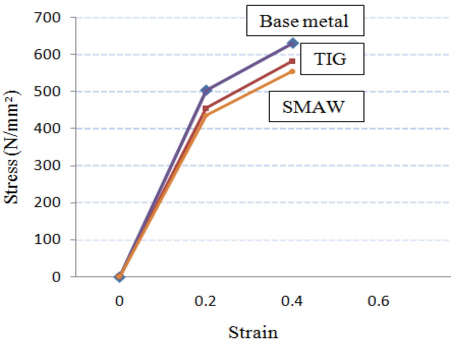


Fig 4.1 Stress strain relationship on result

The SMAW and TIG welding plate tensile properties are given in the graphical view. The curve propagation shows, stress and strain relationship of weld metal, base metal under the load. The graphical representation of weld metal and base metal comparison shown in below figure 4.1Stress Strain Relationship. Both of the tensile strength below the base metal value but the TIG welding better fracture strength than SMAW. So the result said that the TIG welding stainless steel 304 grade having the better tensile strength than SMAW welding.

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