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EFFECT OF WELDING PROCESS PARAMETERS ON TENSILE STRENGTH AND MICROSTRUCTURE ON STAINLESS STEEL DISSIMILAR JOINTS

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ABSTRACT

Gas Tungsten Arc welding (GTAW) process offers a potential for materials which are hard to weld. It is used to join thin sections of stainless steel and non ferrous metals like Al alloys and it is possible to obtain high quality weld for wide variety of metals and alloys. Gas Tungsten Arc Welding is generally used for fabrication of ferritic stainless steel components because it produces a very high quality weld. The majority of armour fabrication is performed by fusion welding process and they demand for highest welding quality. Shielded metal arc welding (SMAW) and the flux cored arc welding (FCAW) processes are widely used in fabrication of combat vehicle construction. Gas Metal Arc Welding (GMAW) is an effective technology used throughout the industry. It is used widely in advanced construction and equipment, especially in the automotive industry to join the parts. The combination of building materials which commonly uses aluminium and steel has high demand for welding technology. The GMAW welding parameters influence the quality, productivity and cost of welding joint. Austenitic stainless steels have been widely used as nuclear structural materials for reactor coolant piping, valve bodies and vessel internals because of their excellent mechanical properties. Ferritic stainless steels are good resistance to cyclic oxidation and to thermal fatigue, due to their low thermal expansion coefficient compared to austenitic stainless steels. However, these ferritic stainless steels generally have lower strength and lower resistance to isothermal oxidation and creep at high temperature. The current study presents some fundamental observations on the effect of welding processes on tensile, microstructure and corrosion behavior of the fusion zone, formed by AISI 304 (ASS) and AISI 430 (FSS) with AWS E308MoL austenitic stainless steel covered electrode, being a dissimilar welding procedure. Such welding configurations are widely used as an overlay of equipment in the petroleum and gas industries. The welding processes carried out in this experiment are Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW), and Gas Metal Arc Welding (GMAW). Samples of the weld metals were conventionally prepared for the microstructural characterization for optical microscope. The tensile properties of the welded material are determined. Based on the results obtained, the optimum welding process for joining ASS and FSS is evaluated.

Keywords: *Austenitic stainless steel, Ferritic stainless steel, Gas Tungsten Arc Welding, Gas Metal Arc Welding, Shielded Metal Arc Welding, Microstructure and tensile test.*

1. Introduction

General

The welding procedure is one of the most important connection techniques available for metallic components. An incredibly wide variety of utensils and structures from the most simple, such as a spoon, to the most complicated, like off-shore platforms, ships or even nuclear reactors, could only be realized by application of one or several welds. It is therefore vital in the development of new materials and applications to optimize and qualify the welding procedure. [1].Welding processes are extensively used to assemble components in many manufacturing industries, such as aeronautics, construction, energy and automotive. To increase their productivity, constructors try to reduce manufacturing time. This involves for welding operations an increase of welding speed [2]. With increasing demand in the application requirements, dissimilar material joining becomes inevitable in engineering industries. There are many issues/problems associated with the joining of dissimilar materials, depending on the materials being joined and process employed. A few of the general problems that are encountered during welding and in the resultant

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weldments are: carbon migration from the higher carbon containing alloy to the relatively lower carbon alloy steels, especially those which are highly alloyed, the differences in thermal expansion coefficients, resulting in differences in thermal residual stresses across the different regions of weldments, difficulty in executing the post weld heat treatment, especially in combinations wherein either of the materials being joined is susceptible to undesirable precipitation at elevated temperatures and electrochemical property variations in the weldment, resulting in environmentally assisted problems [3]. The automotive exhaust system can be divided into two categories, hot and cold end parts, according to their operating temperature. Hot end parts such as an exhaust manifold are used at temperatures higher than 823 K and the maximum temperature approaches 1173 K. The cold end parts such as a muffler and a tail pipe are operated at temperatures below 823 K. Recently, the use of ferritic stainless steels in automotive exhaust systems is increasing in order to meet the requirement for longer guarantee terms, lighter weight, and stricter environmental regulations [4]. The constant evolution of European anti-pollution standards obliges automotive manufacturers to adapt their new vehicles by working on the improvement of engine efficiency and on weight reductions. Some of the investigations carried out to reach these objectives concerns the exhaust system, that have to be lighter and more resistant to high temperatures produced by the increase of engine efficiency. The exhaust manifold is a critical part of the exhaust system, because it supports very high temperatures and corrosive atmosphere. Traditionally made of cast iron in the form of massive components, manifolds can now be made of stainless steel, using tubes or thin sheets rolled and welded. Ferritic stainless steels are well suited for such applications, because they present a good resistance to cyclic oxidation and to thermal fatigue, due to their low thermal expansion coefficient compared to austenitic stainless steels. However, these ferritic stainless steels generally have lower strength and lower resistance to isothermal oxidation and creep at high temperature. In addition, they are sensitive to intergranular corrosion, especially after welding, due to the precipitation at grain boundaries of chromium carbides, creating along the grain boundaries chromium depleted zones more sensitive to corrosion [5]. This is due to the absence of phase transformation during which grain refinement could occur. The problem of grain coarsening in the weld zone of FSS welds is addressed by limiting heat input by employing low heat input and at higher welding speed [6]. A major concern, when welding austenitic stainless steels, is the susceptibility to hot cracking or micro fissuring in the weld metal and heat affected zone (HAZ). This cracking is primarily due to the low-melting liquid phases that allow boundaries to separate under the thermal and shrinkage strains during weld solidification and cooling. Austenitic stainless steel welds exhibit some degree of susceptibility to localized corrosion, pitting and crevice corrosion, and in many cases it is the limiting factor in stainless applications. It is generally accepted that delta ferrite, when present in small amounts in the austenite matrix, is detrimental to pitting resistance by providing favorable sites for pitting initiation in the weld metal. Thus, it is important to investigate the corrosion behavior related to the segregation of weld metal in order to consider its effects on the practical welding of stainless steels [7]. An intense corrosive process was observed in some equipment, especially in distillation towers, which are innerly coated by the AISI 410S ferritic stainless steels. To restore these equipments and to guarantee a good performance in operations, the inner surface corroded are again coated with the application of linings derived from the ferritic and/or austenitic stainless steel, especially those containing high chromium levels and addition of molybdenum [8]. Welds with good mechanical properties and good corrosion resistance are produced as easily and economically as with austenitic stainless steels. Ferritic-austenitic steels, such as 3RE60 and SAF 2205, undergo transformation to increasing amounts of ferrite with subsequent grain growth at temperatures above about 1050°C (1920°F). These reactions will take place in the parts of HAZ heated up to and above this temperature. On cooling, however, austenite will quickly reform, initially at the ferrite grain boundaries but also intergranually. Owing to the well balanced composition of the steels, the coarse ferrite grains are entirely surrounded by austenite. Austenite reformation will also occur within the grains. This is very important as the austenite gives the HAZ good toughness and corrosion resistance in spite of higher ferrite content than in the parent metal [9]. Development of dissimilar weldments represents major challenge in modern manufacturing processes. One of the main reasons for the poor progress in this area is the relative lack of basic understanding of the process. In particular, very little is known about the weldments both in terms of heat transfer, fluid flow and the microstructure development. All these are crucial in developing sound dissimilar weldments in future [10]. Dissimilar metal welding is frequently used to join stainless steels to other metal alloys. This approach is most often used where a transition in mechanical properties and/or performance in service are required [11]. The strength of the dissimilar weldments is generally inferior, most of the in-service failures are reported to take place in the weld region. Such failures in the transition zone between ferritic steel and austenitic stainless steel is a perennial problem in fossil-fired steam plants. Similar and dissimilar joints involving austenitic steels are susceptible to unexpected phase propagation. As a result of this, a series of negative metallurgical changes such as delta ferrite phase, grain boundary corrosion and sigma phase occurs at the weld interface. Therefore, higher welding speeds are necessary to avoid such effects. Sometimes extensive care and precautions are needed such as pre and post heat treatment processes [12]. Austenitic stainless steels have been widely used as nuclear structural materials for reactor coolant piping, valve bodies, and vessel internals because of their excellent mechanical properties. However, welding often leads to low mechanical properties owing to the metallurgical changes such as micro-segregation, precipitation of secondary phases, presence of porosities, solidification cracking, grain growth in the heat affected zone (HAZ) and loss of materials by vaporization. Generally speaking, welding is one of the most widely used processes to fabricate stainless steel structures. The conventional arc welding is often sensitive to form the coarse grains and intergranular Cr-rich carbides along the grain boundaries in HAZ, which deteriorates the mechanical properties of the joints [13]. As a general rule, the ferritic stainless steels are subjected to excessive grain growth in the fusion zone and heat affected zone. This behavior is mainly due to the complete solidification in ferrite mode and negligible phase transformation in the solid state which could help the grain refinement. In fact, after the weld solidification of the 11% Cr ferritic stainless steels a net of austenite is formed along the ferrite grain boundaries at high temperatures, which transformers in martensite on cooling. Nonetheless, this phase transformation is insufficient to avoid the grain growth. Because of the grain coarsening and formation of martensite along the ferrite grain boundaries these ferritic stainless steel welds exhibit poor toughness, ductility and corrosion resistance. In order to apply these linings or weld overlays and to overcome these undesirable situations, the welding procedure for ferritic stainless steels recommends the use of austenitic filler metals, resulting in a dissimilar ferritic/austenitic stainless steel weld metal. In the petroleum, gas and petrochemical industries the AWS E309MoL-16 covered electrodes are frequently utilized for both linings and overlay applications due to high content of alloying elements such chromium, nickel and addition of molybdenum above 2 wt % [14]. Stainless steel or, more precisely, corrosion-resisting steels are a family of iron-base alloys having excellent resistance to corrosion. Stainless-steel sheets are increasingly used for vessels, kitchen, building, transportation, etc., because of their high corrosion resistivity and beautiful appearance. Among them, type 304 stainless-steel sheets are most commonly used for forming products since they are superior in formability. Austenitic stainless steels are one of the best choices, as they combine very good corrosion behaviour with excellent mechanical properties (strength and toughness), especially when using LN grades, characterized by very low carbon levels (to prevent intergranular corrosion phenomena and improve weldability), and nitrogen alloying for increasing their mechanical strength [15].

SMAW

Shielded metal arc welding (SMAW) is the most widely employed joining process in engineering industries, especially in those dealing with structural and piping applications [3]. While both the shielded metal arc (SMA) and flux cored arc (FCA) welding processes are often used in the welding of stainless steels, the FCAW process has come to be used to a greater extent than the SMAW process over the past seven to eight years, due to the possibility of employing inexpensive carbon dioxide as the shield gas [16]. The majority of armour fabrication is performed by fusion welding process and they demand for highest welding quality. Shielded metal arc welding (SMAW) and the flux cored arc welding (FCAW) processes are widely used in fabrication of combat vehicle construction [17]. The heat for SMAW comes from an arc which develops across an air gap between the end of an electrode and the base metal. The air gap produces a high resistance to the flow of current, and this resistance generates an intense arc heat. The filler wire (electrode) forms molten droplets that deposit into the weld. The flux forms a gas that shields the molten weld pool. The arc force provides the digging action for penetration into the base metal. This process continues as the weld widens and the electrode continues across the joint. SMAW is governed by a large variety of factors, and so it is very difficult to gain expertise in SMAW procedures [26].

GTAW

An arc welding commonly used to join metal and its alloys. GTAW process, also known as TIG welding, is most commonly used to join thin sections of stainless steel and non-ferrous metals such as aluminum and magnesium alloys. The process grants the operator greater control over the weld than competing procedures such as SMAW and GMAW, allowing for higher quality welds in a wide variety of metal and its alloys. However, the potential problems of TIG welding lie in the limited thickness of workpiece which can be welded in a single-pass operation [11]. Gas tungsten arc welding is fundamental in those applications where it is important to control the weld bead shape and the metallurgical characteristics. This process is, however, of low productivity, particularly in the welding of large components. Usually, in the TIG welding of stainless steels with argon shielding, full penetration welding is restricted to joints of a maximum thickness of 3 mm and to relatively low welding speed. Although the welding speed can be increased substantially (up to 160%) when helium or hydrogen is used as part of the shielding gas mixture, bead penetration can only be increased slightly (1±2 mm) [18]. Tungsten inert gas (TIG) welding which uses a non-consumable tungsten electrode and an inert gas for arc shielding, is an extremely important arc welding process. It is commonly used for welding hard-to-weld metals such as stainless steel. Basically, TIG weld quality is strongly characterized by the weld pool geometry. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld [19]. In the fabrication of equipment made from stainless steels such as pipe, automotive exhaust gas system, chemical industrial equipment, etc., arc welding using shielding gas is often used. Tungsten inert gas (TIG) welding is one of the commonly used welding methods [20]. Tungsten inert gas (TIG) welding has long been recognized as a modern high-quality industrial process. Research on the improvement of penetration using the TIG process has been ongoing for decades. Welding speed, current and arc length are important parameters of the TIG welding process. The effects of these parameters play a main role on the weld pool shape [21]. Austenitic characteristics consisting of grain orientation distribution and anisotropy show that the GTAW specimen is more isotropic than the SMAW due to the orientation of its grains [22].

GMAW

The welding of exhaust systems, generally using a Gas Metal Arc Welding (GMAW) process, can change the materials characteristics. The local heating and rapid cooling induced by welding create a ‘‘Heat Affected Zone’’ (HAZ) around the fusion zone, presenting microstructure changes [3]. In gas metal arc welding (GMAW), the common variations of shielding gases, power supplies and electrodes have significant effects resulting in several different and important process variations [15]. It is a once welding process that uses an arc between a continuous filler metal electrode and a weld metal. The process is used with shielding from an externally supplied gas and without the application of a pressure; it was developed in the late 1940 s for welding aluminum and has become very popular. This process is also called metal in arc gas (MIG) welding .There are many variations depending on the type of shielding gas, type of the metal transfer, type of the metal welded and so on. It has been given many names for example (MIG Welding, Co2 welding, Fin wire welding, Spray arc welding, Pals arc welding, Dip transfer welding, Short circuit arc welding and various trade names) [23]. Metal inert gas welding is an effective technology used throughout the industry. It is used widely in advanced construction and equipment, especially in the automotive industry to join the parts. The combination of building materials which commonly uses aluminium and steel has high demand for welding technology [24]. Gas Metal Arc Welding (GMAW) process is leading in the development in arc welding process which is higher productivity and good in quality. A Metal Inert Gas (MIG) also called GMAW is the process that included of heating, melting and solidification of parents metals and a filler (wire electrode) material in restricted fusion zone by transient heat source to form a joint between the parent metals. The continuous wire electrode from an automatic wire feeder and fed through the contact tip inside the welding torch is melted by the internal resistive power and heat transferred from the welding arc. Heat determined from the end of the melting electrode to molten weld pools and by the molten metal that transferred to weld pools. The GMAW welding parameters influence the quality, productivity and cost of welding joint. The perfect arc will be achieved if all the welding parameters in conformation. These parameters consists of arc welding current, arc voltage, welding speed, torch angle, free wire length, nozzle distance, welding position and direction and lastly the flow rate of gas. From the previous study with an MIG or GMAW welding process, it observed that the depth of penetration increased when the welding current is increased but decreased with decrease in voltage and the penetration increased when arc travel rate decreased until it attained a minimum value depends on the arc power [25].

2. Experimental Procedure

In this experiment, Lincon electric power wave 455M/STT for GMA welding and Precision TIG 375 for GTA welding were used. In this study, 304 austenitic stainless steel and 430 ferritic stainless steel specimens 4mm in thickness were welded to each other by gas tungsten arc welding, gas metal arc welding and shielded metal arc welding using E308L as filler material. The chemical composition for the base material and filler material are given in Table 1. First the stainless steel specimens in 150X75X4 mm3 dimensions were cut and the edge to be bonded were chamfered at 350. Surfaces of machined samples were cleaned and then placed adjacent to each other by 2-mm distance. SMAW was carried out by keeping welding current of 120A, voltage of 17V and welding speed of 3.5mm/s. GTAW was carried out by keeping welding current of 140A, voltage of 20V, tungsten electrode of 2.4mm diameter, arc gap of 3mm and welding speed of 37.5 mm/min. GMAW was carried out by keeping welding current of 150A, voltage of 23V and welding speed of 4.17mm/s. The shielding gas used in both GTAW and GMAW process is CO2 at the gas flow rate of 15kgf/cm2. During SMAW, the welding is done manually throughout the experiment. In GMAW, wire feed rate was controlled automatically and welding process is done manually. In GTAW, welding gun was controlled automatically and the welding wire was fed manually into the welding area. The welded samples by different welding process are shown in Fig.1, Fig.2, and Fig.3.

Table 1: Chemical composition of base material and filler material

Base metal	C	Cr	Fe	Mn	Ni	P	S	Si	Mo
304	0.04	18.5	Balance	1.6	9.5	0.025	0.02	0.45	-
430	0.05	17	Balance	0.77	0.5	0.030	0.020	0.50	-
E308L	0.03	20	Balance	1.75	10	0.03	0.025	0.8	0.7

Fig. 1 Welded sample by SMAW

Fig. 2 Welded sample by GMAW

Fig. 3 Welded sample by GTAW

Fig. 4 Tensile samples from the welded plates

Fig. 5 Microstructure samples from welded plates

As it is seen from Fig.4, the welded samples were cut into pieces for tensile test and microstructure examination from Fig.5. Tensile testing samples were prepared according to the ASTM E8-04. Standard metallographic grinding was applied and then grinded samples were etched by using kroll and aqua regia solution. Microstructure was taken by using optical microscope. Hardness measurements were performed on the samples which were used for microstructural examination.

Table 2: Tensile testing results

Process	Ultimate tensile strength (kN/mm^2)	Yield strength (kN/mm^2)	Elongation (%)
SMAW	0.452	0.412	16.500
GTAW	0.470	0.468	18.588
GMAW	0.398	0.372	20.650

3. Results and Discussion

3.1 Tensile test

Results of bonded samples, which were welded under different welding conditions, are given in Table 2. From that the highest tensile strength and yield strength is 0.470kN/mm^2 and 0.468kN/mm^2 respectively which were welded by GTAW process. Other two welding process SMAW and GMAW have tensile strength of 0.452kN/mm^2, 0.398kN/mm^2 and yield strength of 0.412kN/mm^2, 0.372kN/mm^2 respectively. The tensile test results of GTAW, GMAW and SMAW are shown in Fig.6, Fig.7 and Fig.8 respectively. In GMAW, the fracture occurred in the HAZ near the parent material, 430. In other cases, the fracture occurred in the base material, 430. That result, the weld region possesses good strength than that of base material. The high strength in the welded region is due to the presence of molybdenum content in the filler material. The lower strength in the sample welded by GMAW is due to availability of porosity in the weld pool.

Fig. 6 Tensile test result for GTAW

Fig.7 Tensile test result for GMAW

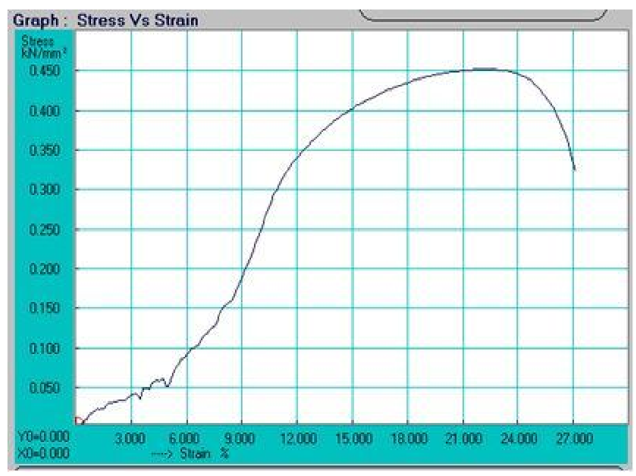

Fig. 8 Tensile test result for SMAW

3.2 Microstructure characterization

SMAW

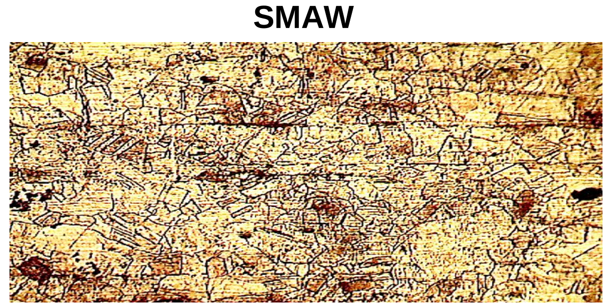

Fig. 9(a) Microstructure of 304

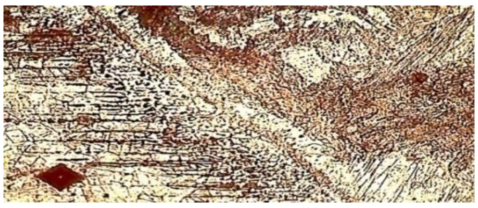

Fig. 9(b) Microstructure of HAZ

Fig. 9(c) Microstructure of weld region

Fig. 9(d) Microstructure of HAZ

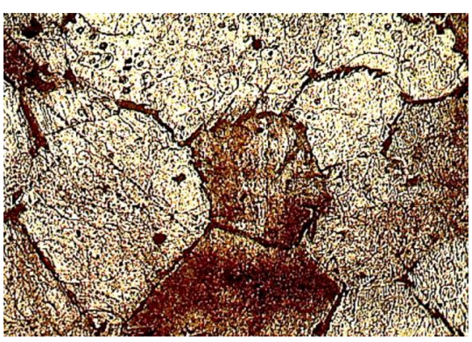

Fig.9(e). Microstructure of 430

Magnification: 150X,

Etchant: Kroll & Aqua Regia Solution

Fig. 9(a) shows the microstructure of the S.S. 304 matrix. The material as rolled sheet and the longitudinal rolling direction is shown by the austenite grains with stringers between the grains which are tapped during the rolling. Fig. 9(b) shows the interface zone of the s.s and the weld metal. The heat affected zone is seen at the s.s. side and it is partially re-crystallized at the zone. Fig. 9(c) shows the weld metal matrix with the presence of fine dendrite pattern. The weld consists of austenite with some ferrite islands. Fig. 9(d) Shows the inter face zone of ferritic stainless steel matrix. The ferritic SS alloy re-crystallized due to heat and the grains are larger at the heat affected zone. The grains are completely ferritic with some carbide of chromium. Fig. 9(e) Shows the microstructure of ferrtic ss alloy with ferrite phase. The ferrite grain is white and the carbide grain is black.

GMAW

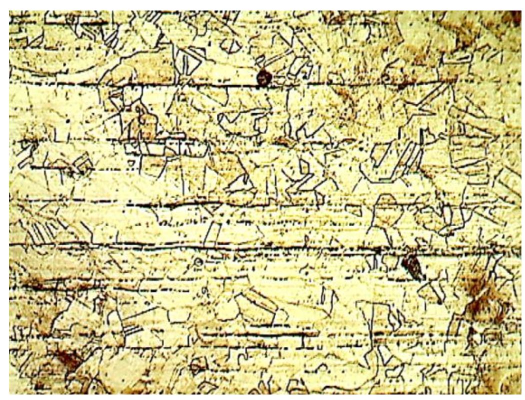

Fig.10(a). Microstructure of 304

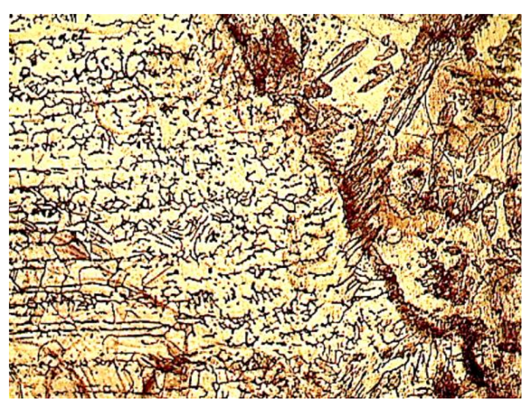

Fig.10(b). Microstructure of HAZ

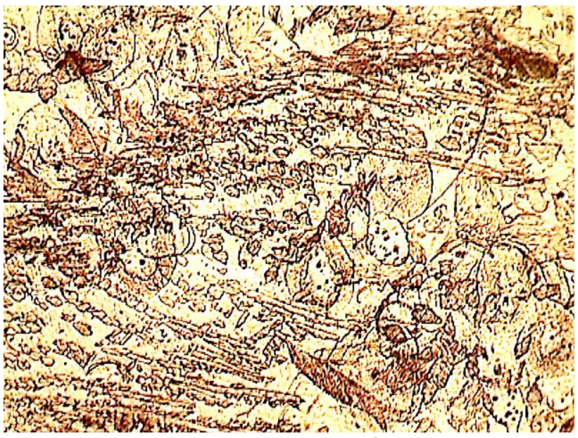

Fig.10(c). Microstructure of weld region

Fig.10(d). Microstructure of HAZ

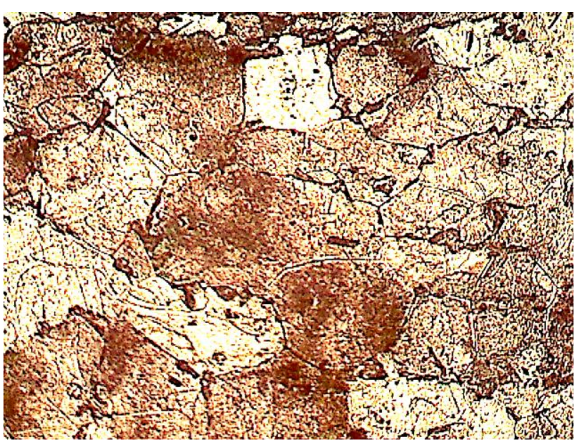

Fig.10(e). Microstructure of 430

Magnification: 150X

Etchant: Kroll & Aqua Regia Solution

Fig.10 (a) shows the microstructure of the S.S. 304 matrix. The material as rolled sheet and the longitudinal rolling direction is shown by the austenite grains with stringers between the grains which are tapped during the rolling. Fig.10 (b) shows the interface zone of the s.s and the weld metal. The heat affected zone is seen at the s.s. side and it is partially re-crystallized at the zone. Fig.10 (c) shows the weld metal matrix with the presence of fine dendrite pattern. The weld consists of austenite with some ferrite islands. The dendrite are coarser due to slower rate of cooling. Fig.10 (d) shows the inter face zone of the ferritic SS alloy. The ferritic SS alloy re-crystallized due to heat and the grains are larger at the heat affected zone. The grains are some ferrite and carbide. Fig.10 (e) shows the microstructure of ferritic SS alloy with ferrite and carbide grains. The ferrite grain is white and the carbide grain is black. The grain of ferritic SS alloy is smaller.

GTAW

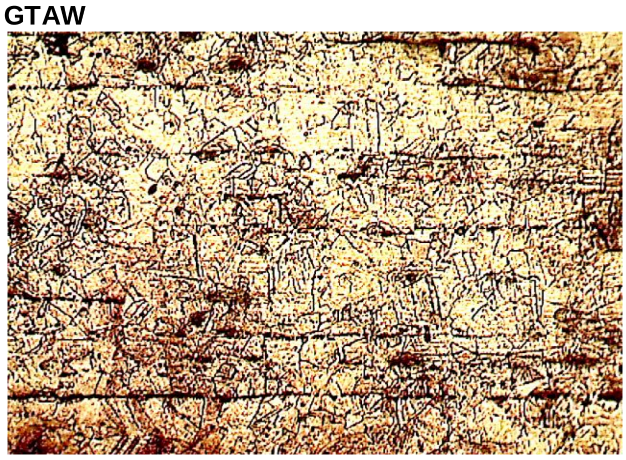

Fig.11(a). Microstructure of 304

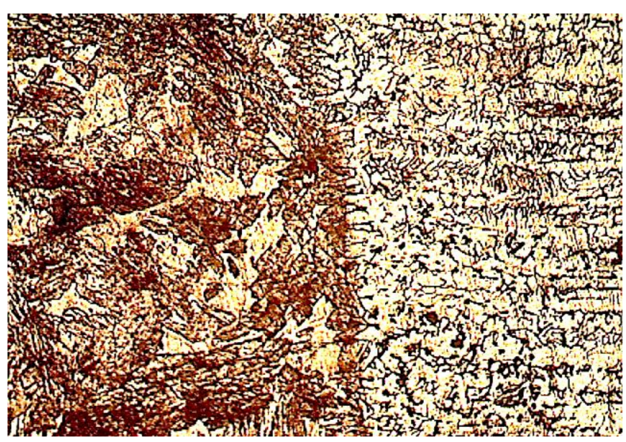

Fig.11(b). Microstructure of HAZ

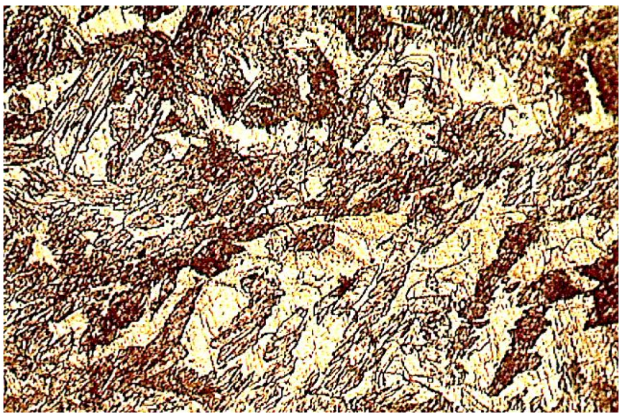

Fig.11(c). Microstructure of weld region

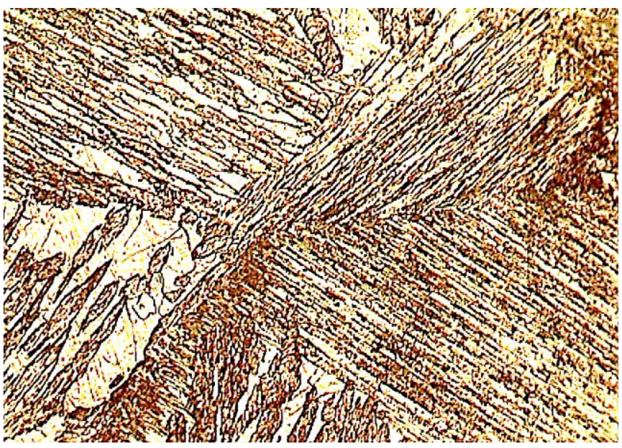

Fig.11(d). Microstructure of weld region

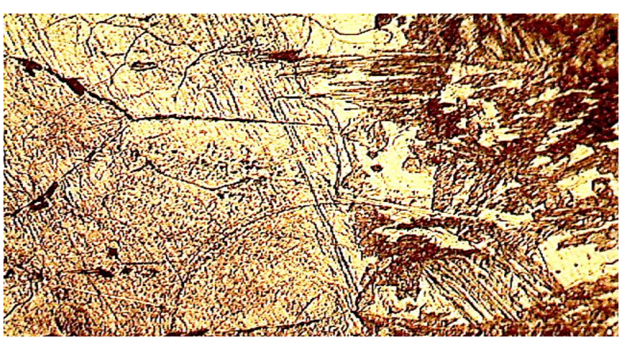

Fig.11(e). Microstructure of HAZ

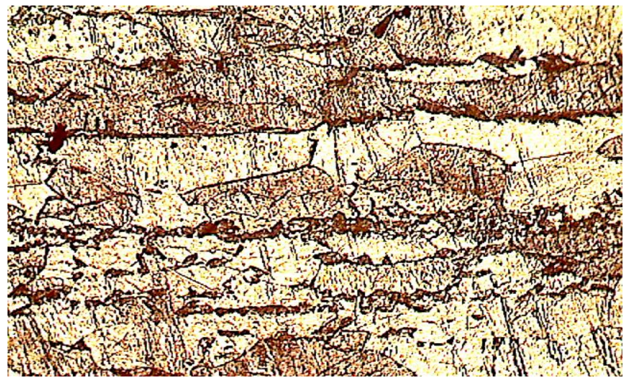

Fig.11(f). Microstructure of 430

Magnification: 150X

Etchant: Kroll & Aqua Regia Solution

Fig.11 (a) shows the microstructure of the S.S. 304 matrix. The material as rolled sheet and the longitudinal rolling direction is shown by the austenite grains with stringers between the grains which are tapped during the rolling. Fig11 (b) shows the interface zone of the s.s and the weld metal. The heat affected zone is seen at the s.s. side and it is partially re-crystallized at the zone. Fig11 (c) shows the weld metal matrix with the presence of fine dendrite pattern. The weld consists of austenite with some ferrite islands. Fig11 (d) shows the weld metal microstructure have very large dendrites with coring along the parent metals. Fig11 (e) shows the inter face zone of the ferritic SS alloy alloy. The ferritic SS alloy re-crystallized due to heat and the grains are larger at the heat affected zone. The grains are some ferrite and carbide. Fig11 (f) shows the microstructure of ferritic SS alloy with ferrite and carbide grains. The ferrite grain is white and the carbide grain is black.

3.3 Macrostructure characterization

Fig. 12 (a) GTAW

Fig.12 (b).GMAW

Fig.12 (c).SMAW

Fig.12 (a) shows the macro structure of GTA welded sample. The flow lines are viewed clearly from the picture. The base material flow towards the weld region and the HAZ is small in 304 and large in 430. The heat concentration is more in 430 because the formations of crystal like structure in a narrow condition. Fig.12 (b) shows the macro structure of GMA welded sample. As in GTAW, the HAZ is much in 430 when compared to the HAZ in 304. Fig.12 (c) shows the macro structure of SMA welded sample. The material flow from the base material to the weld pool can be seen exactly. In this weld also, the HAZ is much in 430 because the carbon formation can be viewed in the HAZ.

3.4 Microhardness test

The micro hardness (VHN) test was performed on the etched transverse cross-section of the weld zone using a load of 0.5 kg, which was applied for duration of 20 s. The average value of the hardness is shown in Table 3.

Table 3: Micro hardness test (VHN)

Process	Distance @1mm	VHN @0.5 kg load (average)
SMAW- 430	0-8	177.685
Weld region	9-17	227.345
304	18-25	209.40
GMAW- 430	0-8	178.25
Weld region	9-17	244.135
304	18-25	218.29
GTAW- 430	0-8	187.76
Weld region	9-17	284.215
304	18-25	209.265

From the Table 3, it clearly shows that the hardness of the weld region is higher when compared to the base material. The reason is the dissimilar combination in the weld pool possesses good strength against toughness than that of base material because of the fine grain size in the welded region.

4. Conclusion

On the basis of the mechanical properties and microstructural experimental studies accomplished and the results obtained on the effect of welding processes on dissimilar welded joints of stainless steel the following conclusions may be drawn:

1. For tensile strength, the best strength is obtained from GTAW process when compared to GMAW and SMAW. The ultimate tensile strength is 0.470kN/mm2 and yield strength is 0.468kN/mm2.

2. In tensile test, the fracture occurred in base material, 430. Hence, the weld possesses good strength against toughness.

3. The hardness in the weld metal is higher than that of base material. The reason is the dissimilar combination in the weld pool possesses good strength against toughness than that of base material because of the fine grain size in the welded region.

4. From the macrostructure, the flow lines are formed from base material towards the weld pool. The HAZ is very large in 430 and very small in 304. The fine crystal like structure can be viewed in the macrostructure shows the presence of carbides.

5. In the microstructure, the fine grain flow shows good formation of the weld in the joint. The elongation of grain size is due to high temperature. The direction of flow of grains is from base material towards the weld pool.

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