ANALYSES OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF LOW ACTIVATION MARTENSITIC STEEL JOINT BY TIG MULTI-PASS WELDING WITH A FILLER WIRE

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Abstract: Tungsten Inner Gas (TIG) welding is employed for joining of low activation martensitic (LAM) steel. A filler wire was proposed, and the investigation on welding with various heat input and welding passes were conducted to lower the tendency towards the residual of ferrite in the joint. With the optimized welding parameters, a butt joint by multi-pass welding with the filler wire was prepared to investigate the microstructure and mechanical properties. The microstructure of the joint was observed by optical microscope (OM) and scanning electron microscope (SEM). The hardness, Charpy impact and tensile tests of the joint were implemented at room temperature (25 °C). The results revealed that almost full martensite free from ferrite in the joints were obtained by multipass welding . A certain degree of softening occurred at the heat affected zone of the joint according to the results of tensile and hardness tests. The as welded joints showed brittle fracture in the impact tests. However, the joints showed toughness fracture after tempering and relatively better comprehensive performance were achieved when the joints were tempered at 740 °C for 2 h.

***Keywords**:* (Low Activation Martensitic) LAM steel, Filler wire, TIG, Multi pass welding

I. Introduction

Gas tungsten arc (GTA) or tungsten inert gas (TIG) welding process is one of the most common permanent metal joining processes used for welding of stainless steels, titanium alloys, aluminum alloy sand other non-ferrous metals because of its good quality weld and low cost equipment. It is popular to weld thin sections and can be used for various welding positions such as horizontal, vertical and overhead and also popular to produce a smooth hand clean weld. Although the process attributes several advantages, low weld penetration renders it less appropriate for industrial use. To overcome the limitation of low penetration in a single pass, groove design and Multi pass is required to weld thick sections which decrease productivity of the process and increase cost of production. Tungsten inert gas (TIG) welding performance can be improved with an inorganic powder named 'activating flux', which is laid on the metal before welding. One of the most notable techniques is the use of activating flux in TIG welding process. 90–95% application of activating fluxes has been reported in A-TIG process. The A-TIG welding totally eliminates filler wire addition, reduces edge preparation time and enhances the penetrating power in the weld pool. Hence, single pass weld with higher welding speed can be achieved.

1.1 Mechanism of TIG welding

It is also called as tungsten inert gas welding. It is an arc welding process where coalescence is produced by heating the work-piece with an electric arc struck between tungsten electrode and work-piece. To avoid atmosphere contamination of the molten weld pool, a shielding gas is used. If required, a filler metal may be added. In this process non consumable tungsten electrode is used. First of all current supply and shielding gas switch on. Afterwards with base metal the tungsten electrode strike for producing arc, when tungsten end and base metal between gap is maintained at a 2-3 mm then sufficient arc will be produce. Then provided shielding gas protect the weld part to atmosphere to resist oxidation of weld.

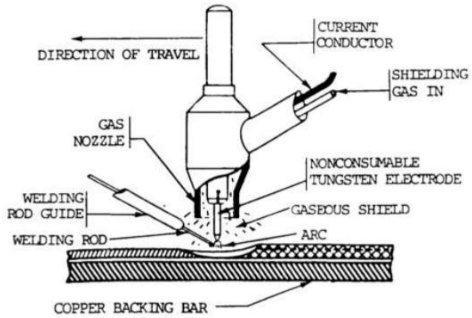


Fig. 1. TIG Welding mechanism

1.2 Procedure for LAM steel TIG application

Mix the oxide powder with acetone in a 1:1 weight ratio,to produce a paint-like consistency. The ratio of flux pow-der to carrier solvent is not critical, it must be mixed to a consistency that can be “painted on” .The flux mixture will thicken over time as the acetone evaporates. Add more acetone as needed to return the mixture to the proper consistency. Using the small paint brush, apply oxide powder to the center of the plate. The layer should be sufficiently thick so that the flux appears. The layer should be slightly wider than the anticipated width of the weld bead. Flux should sufficiently be adhered to the surface to combine TIG to be used in all position. During welding, arc length has to be maintained as per welding procedure specification. After welding, any unconsumed flux can be removed with ease. Flux that has been consumed by the arc creates a tenacious layer. A residual slag typically remains on the top surface to the weld pool can be removed by grinding or aggressive wire brushing Tungsten as long lasting electrode and inert gas for shielding arc are main components in tungsten inert-gas (TIG) welding where the tungsten electrode incurs an electric arc with the workpiece material to generate the heat required to melt down which is shielded by an inert gas. The trustworthiness and properties of the TIG welding are superior to that of any other arc welding methods. Duplex type filler material can be used during TIG welding of LAM steel. This produces more austenitic structure at the TIG WM compare to other types of welding where no filler material is used.

The picture of fusion zone of LAM steel is shown in Fig.2 which shows that the structure of this zone comprises of austenite phase precipitated within ferrite phase where solidified substructure borders are visible due to quick dispersion of alloying and contaminating elements. divided the heat affected zone (HAZ) into partially annealed and overheated zones. The overheated zone (very near to the fusion boundary) consists of a lesser quantity (25%) of austenite compare to the melted and partly annealed regions which is because of the too high topmost temperature in this zone. The phase transformation of this area takes place partially during cooling where the time is insufficient for chromium to disperse all through the ferrite phase. The partly heat treated area of the HAZ consists of substantial development of grain compare to that of base metal (Fig. 8). It seems that the heating of this portion of the HAZ takes place above the solution annealing temperature and large amount of ferrite transforms into austenite on cooling. Generally, the central region which experience slower cooling rate compare to the fusion boundaries contains high amount of austenite.

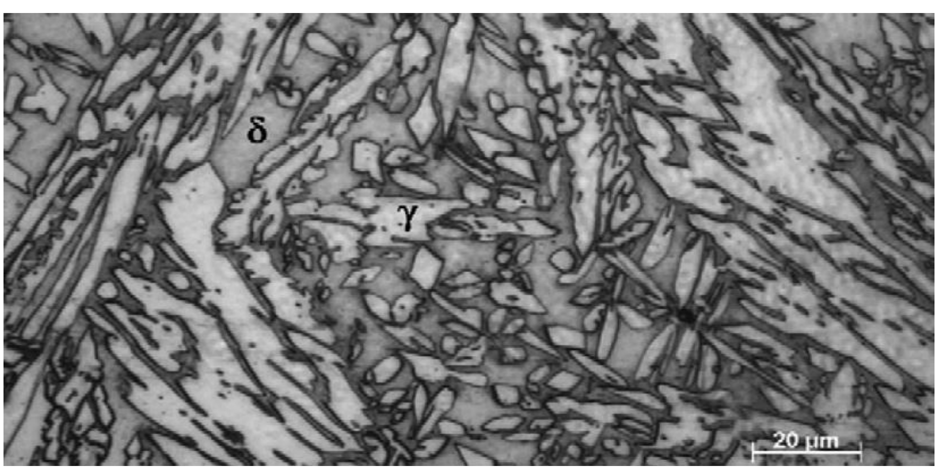
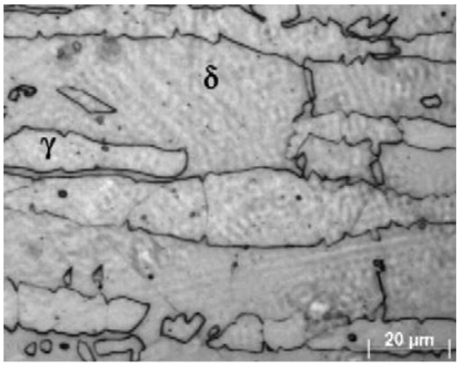


Fig. 2 Fusion area in LAM steel



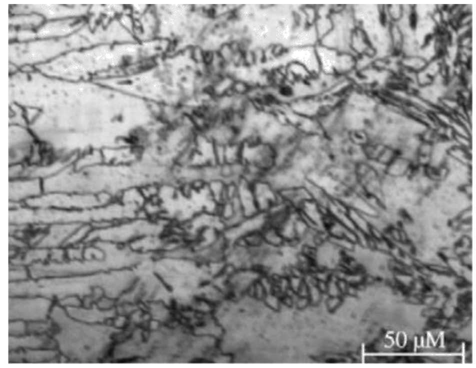


Fig. 3 Structures of (a) partially annealed and (b) overheated part of the HAZ

TIG welding generates thick austenitic phase in the WM (weld metal) as it has a strong austenite forming power. This may introduce nitrogen in WM which was confirmed with the ferrite content measurements of 30-35% in the WM by TIG. It is already mentioned that the amount of ferrite is controlled by the composition of WM, the rate of cooling and heat input during welding. The amount of heat applied in TIG welding generally varies from 3.5 to 4.1 kJ/mm which is higher than the upper limit (3.45 kJ/mm) endorsed by the producers of steel [48]. Thus, the higher heat input deteriorates behaviours of the weldings. However, these can be improved by reducing the runs of welding which ultimately reduce the number of heating and cooling cycles while heating was done to a certain limit of temperature. In addition to annealed the WM, HAZ, and BM of LAM steel at 850°C and noted the sigma phases at the interfaces of ferrite-austenite phases. These interfaces are privileged nucleation locations for the dissimilar formation of intermetallic compounds. The sigma structures in LAM steel form the breakdown of δ ferrite by eutectoid conversion and it grows on the neighbouring δ ferrite phases after the nucleation process. The precipitation of carbides also occurs first at the δ-γ interfaces, and develops on the δ ferrite grains. The formation and development of carbides are supplemented through movement from interfaces of δ-γ structures into the δ phase . No intermetallic phases were noted and the microstructure comprises ferrite and austenite phases after one hour 1050 °C anneal. The grain size of δ ferrite increases significantly compared to austenite grain when the annealing temperature increases from 1050 to 1200 °C though the destruction of the unique banded structure was noted at this temperature range.

The effects of various gas on the microstructure of the welds were investigated. Usually nitrogen is lost and presence of the element that stabilizes ferrite is noted when the shielding gas argon is applied in GTAW (gas tungsten arc welding) joints. This causes uneven balance in the two phases. Thus higher percentage of ferrite is noted because of the higher amount of Mn. Nitrogen plays an important role as an active stabilizer of austenite and the weldability of duplex steel is enhanced by adding this element at raised temperature. The austenite phase is generated in three modes from ferrite. These are allotrimorphs side-plates and intragranular precipitates which depend on the applied heat and temperature cycles. The required amount of nitrogen can be maintained by selecting right amount of heat and temperature cycles to reduce the difference between ferrite and austenite content in the Ar-shielded welding compared to that of He-shielded welding. In addition, the grains of the Ar-shielded weld metal are of better-quality. It demonstrates that the austenite in the weld metals are either intragranular precipitates which are diagonal to the long-axis. Higher amount of austenite in the helium-shielded welding than that in Ar-shielded welding is because of the energy-rich arc in helium-shielded welding.

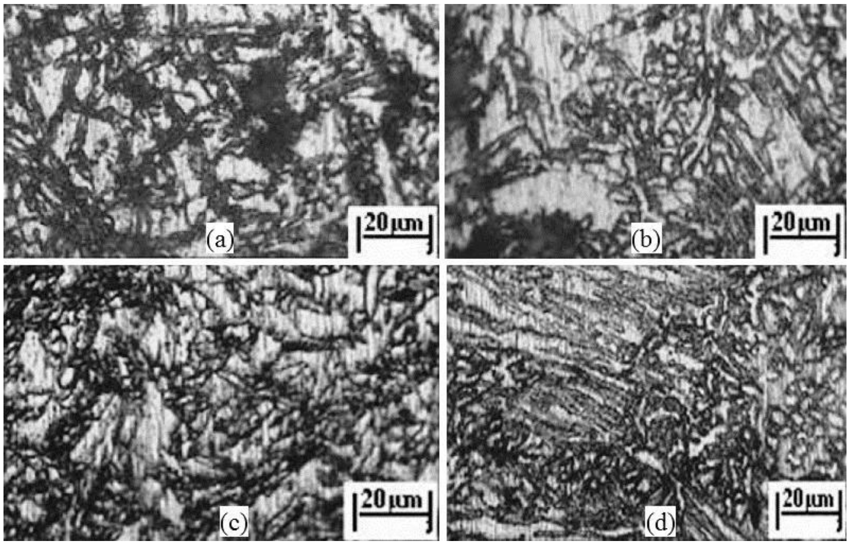


Fig. 4 (a) Ar-shield weld metal, (b) Ar-shield heat affected zone, (c) He-shield weld metal (d) He-shield heat affected zone

Conventional TIG welding can be improved. This is known as LAM steel TIG welding. Oxide, chloride, and fluoride powders are generally are dissolved into acetone or ethanol . This enlarges the penetration by 200–300% which reduces the weld time, costs and variation of base material constituents. Variation of the autogenous TIG welding process by using thin layer of the filler material made of oxides of Ti, Mn, Si, Mo, and Cr to LAM steel. The structure of the hot rolled LAM steel plate consists of 45.9% and 54.1% ferrite and austenite respectively. The percentages of these two phases in the LAM steel with various types of filler materials after welding are shown. It shows that the percentage of ferrite improved from 45.9 to 63.4% after TIG weld in different filler material.. This is due to solidification of this material as delta ferrite. Due to higher rate of cooling, the conversion to austenite from delta ferrite was incomplete which resulted higher amount of ferrite in weld metal.

2. Material selection

LAM steel is selected over other materials because of its distinct properties, cheaper cost and its availability in market. This grade has high corrosion resistance and can be operated at elevated temperature. The work piece detail is as under:
Diamensions of specimen: 60mm*30mm*6 mm
No. of specimens: 4

3. Conducting the experiments as per design matrix

In the present work, plates of LAM of 6mm thickness and 60 mm lengths were butt joined using three different types of filler rod and three levels of welding current on three different types of groove design by manual TIG welding process. This three parameters were taken as variable for present study and their three levels were chosen for which responces were measured, for which L9 orthogonal array was selected as experimental design method.Before welding all sheets were cleaned chemically by acetone in order to remove any source of contaminants like rust, dust,

Experiment No.	Welding current	Groove design	Filler rod
1	120	V	ER304L
2	120	U	ER308L
3	120	V&U	ER309L
4	150	V	ER308L
5	150	U	ER309L

Table 1. Experimental observations

3.1. Impact test

TIG welded lam samples of 6 mm thickness are subjected to Izod impact tests at room temperature. The specimens with diamensions of 55mm*10mm*5mm.Three specimens from each welded plates were taken for impact testing. Average of these three impact values was taken. Impact test on the weld specimen was performed on the impact testing machine having a range of 0-30 Kgm or 0-300 joules.

3.2. Rockwell hardness test

Hardness was defined as the resistance of a material to plastic deformation usually by indentation. Before hardness test, we need to make smooth the surface of piece which we

Ex. No.	Impact strength(Joules)	Hardness(HRB)	Aspect ratio
1	110	94	0.69
2	92	90	0.77
3	112	85	0.58
4	100	90	0.68
5	98	95	0.71

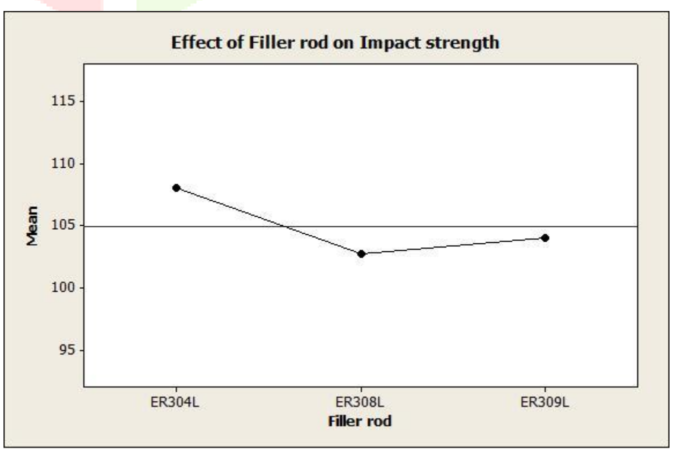
Table 2. Experimental observations

4. Conclusion

The main challenges to obtain optimum fraction of ferrite and austenite phases during welding of LAM are to control the heat input, cooling rate and composition of the workpiece materials/filler materials/shielding gas. The heat treatment of the weld is the last resort to fix the desired balance of ferrite and austenite phases in duplex stainless steel welds. The following conclusions are aroused base on the analysis of the different welding methods of different duplex stainless steel.

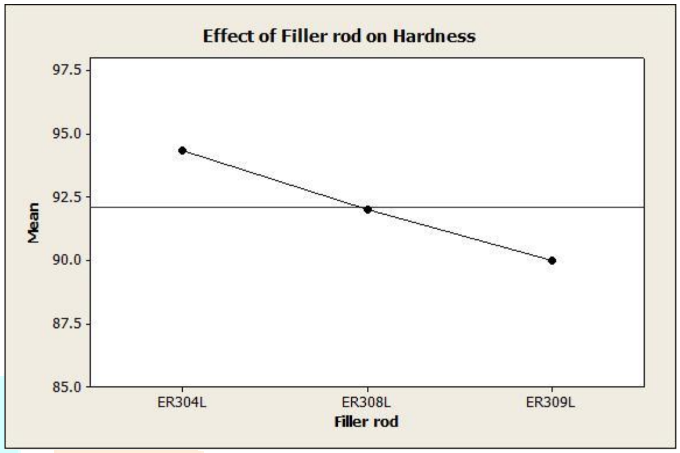
- **The Effect of Filler rod on Impact strength**

Mean effect plot shows that ER304L filler rod has higher impact strength and lower impact strength for ER308L filler rod. For ER309L filler rod, impact strength value is between the previous two filler rod impact strength value. Filler rod is the second influencing parameter to the impact strength, which can be conclude from ANOVA results.



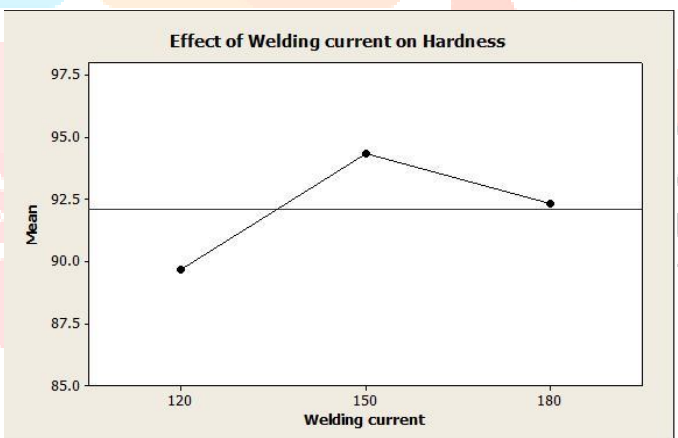
➢ The Effect of Filler rod on Hardness

Mean effect plot shows that ER304L filler rod has higher hardness and lower hardness for ER309L filler rod. For ER308L filler rod, average hardness value is obtain. Filler rod is the second influencing parameter to the hardness,



➢ The Effect of Welding current on Hardness

Welding current is the most influencing parameter to the hardness. Maximum hardness is achieve for 150 A Welding current. Welding current increases from 120 A current to 150 A, hardness increases but further increment in current, the hardness would be decrease. From the plot, it can be concluded that 150 current range is the best for higher hardness achievement.



(a) Greater fraction of ferrite is generally formed during laser welding of LAM, such as 2101, 2205, and 2304. An acceptable amount of austenite can be formed by a cooling rate of 30 to 10 °C/s.

(b) It seems that the resistance welding and submerged arc welding have the capability to produce optimum weld structure though further research on this method is required as much information is not available on this method.

(c) Most researches on welding of LAM are noted in the field of tungsten inert-gas (TIG) welding. Generally the ferrite content is low and intermetallic compounds are deposited in the ferrite-austenite interface during the conventional TIG welding. The shielding by argon gas gives better ferrite-austenite structure in the welding. The ferrite–austenite stability of WM and HAZ is better for TIG than that of laser beam welding. However, the extent of WM and HAZ is lesser for the laser beam welding than that of TIG.

(d) The cladding of duplex stainless steel by TIG does not give expected structure unless it is heat treated. The pulsed DC current gives higher amount of ferrite compare to that of DC current.

(e) Friction stir welding is the only solid state process applied to duplex stainless steel. This method produced a structure of 51% austenite and 49% ferrite for 2205 grade duplex

5. Literature Review

Visvesh J Badheka et al; they have study and observed depth of weld penetration and bead width using A-TIG welding. They had taken fluxes as a CaO, Fe_2o3, Tio_2, ZnO, MnO_2 and CrO_3. From their observation they concluded that increasing in penetration and the decrease in bead width are significant with the use of the activating fluxes Fe_2O_3, ZnO, MnO_2 and CrO $_3$ and maximum depth to width ratio (aspect ratio) they achieved using ZnO, MnO_3 and CrO_3 are 0.95, 0.85 and 0.83 respectively. In case of normal TIG they secured 0.29. They have conduct this experiment with 200A weld current, 160A creater current, 100 mm/min travel speed pure argon shielding gas experiment were carried out by them on 6mm P91 plates. They concluded that arc constriction plays major role in depth of penetration. [1]

R kumar et al; from their review they had concluded that During TIG welding the surface tension gradient is negative and the convection movements are centrifugal and it leads to shallow penetration. The addition of activated flux induce an inversion of the convection currents changing the sign of the surface tension gradient, resulting convection movements changed to centripetal. Hence, the penetration depth increases. They have studied that TIG welding with SiO2 and MoO3 fluxes achieves an increase in weld depth and a decrease in bead width respectively. The SiO2 flux can facilitate root pass joint penetration. Without activating flux weld depth achieved is very less and bead width is unnecessarily high. [2]

Hung Tseng et al; investigated the influence of oxide-based flux powder and carrier solvent composition on the surface appearance, geometric shape, angular distortion, and ferrite content of austenitic stainless steel tungsten inert gas (TIG) welds. The flux powders comprising oxide, fluoride, and sulfide mixed with methanol or ethanol achieved good spread ability. For the investigated currents of 125 to 225 A, the maximum penetration of stainless steel activated TIG weld was obtained when the coating density was between 0.92 and 1.86 mg/cm2. The results show that higher current levels have lower ferrite content of austenitic stainless steel weld metal than lower current levels. [3]

R. Ebrahimi et al; the addition of an activating flux led to an increase in the penetration depth and a decrease of the width. Simulations showed the Marangoni effect combined with Lorentz forces in TIG and A-TIG welding processes. The results of experiments agreed with the simulation conducted for TIG welding. A-TIG weldment exhibited mechanical properties (including strength, ductility, and hardness) better than those of TIG welding without flux. [4]

Heiple et al; revealed that surface active elements in the molten pool change the temperature coefficient of surface tension from negative to positive, thereby reversing the Marangoni convection direction from outward to inward. As the direction of the fluid flow in the molten pool becomes inward, the joint penetration increases dramatically. [5]

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