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GAS TUNGSTEN ARC WELDING AND PLASMA ARC WELDING OF DUPLEX STAINLESS STEEL

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ABSTRACT

To study the welding characteristics of Duplex stainless steel (S2205) plate of 8 mm thickness by performing Gas tungsten arc welding(GTAW) and Plasma arc welding(PAW) .Vickers Microhardness Test, Bend test, Microstructure analysis are done in order to obtain the welding characteristics. The joint fabricated by the Gas Tungsten arc welding (GTAW) is found to have higher hardness in the weld region when compared to the joints fabricated by Plasma arc welding (PAW) process. To evaluate the quality of weld as a function of ductility, bend test is performed and breakage report is obtained. Microscopic examination was conducted to study the material behaviour in the Base metal, Heat affected zone (HAZ) and Weld zone of the welded sample. The major weld defects occurring in the joints fabricated by Gas tungsten arc welding (GTAW) and Plasma arc welding (PAW) processes was determined by Radiographic Testing.

Keywords: Duplex Stainless Steel, GTAW and PAW

1. Introduction

Welding is a fabrication process used to join materials, usually metals together. During welding, the pieces to be joined (the work pieces) are melted at the joining interface and usually a filler material is added to form a pool of molten material (the weld pool) that solidifies to become a strong joint. Gas Tungsten Arc Welding (GTAW) is a process that uses a non consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas, and a filler metal that is fed manually is usually used. The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion can occur.

Plasma Arc Welding (PAW) is an arc welding process that employs a high temperature, constricted plasma gas column to obtain the melting and coalescence of most metals. This column of plasma is constricted by an orifice placed downstream of the electrode. Thermal plasma consists of electrons, ions and neutral particles under high temperature and subject to a disordered violent movement. The plasma is concentrated in the inside of the jet, thereby delivering a narrow plasma jet with a very high density. PAW is used in three modes:

Micro Plasma-0 to 15A: The micro plasma arc can be operated at very low welding currents. The columnar arc is stable even when arc length is varied up to 20mm.

Medium Current-15 to 200A: At higher currents, from 15 to 200A, the process characteristics of the plasma arc are similar to the TIG arc, but because the plasma is constricted, the arc is stiffer.

Keyhole Plasma-over 100A: By increasing welding current and plasma gas flow, a very powerful plasma beam is created which can achieve full penetration in a material, as in laser or electron beam welding. During welding, the hole progressively cuts through the metal with the molten weld pool flowing behind to form the weld bead under surface tension forces.

TIG and PAW are similar processes. Both Welding process (TIG and PAW) uses non consumable Tungsten electrode.PAW uses a slightly different welding torch to create a more focused welding arc than TIG. The temperature obtained in a plasma jet torch may be of the order of 50000^0F against about 10000^0F in ordinary electric welding arc.

2. Literature Review

Review of various works mainly concerned with mechanical properties of materials and welding parameters for Gas Tungsten Arc welding and Plasma Arc welding are as follows:

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[1].Terry A.DeBold has evaluated the Duplex steel including phases of austenite and ferrite in annealed and welded conditions and their properties are studied for boiler and pressure vessel service.

[2].Jerzy Nowacki and Pawel Rybicki has studied the influence of the heat input for submerged arc welding (SAW) of duplex steel on welded butt joints by radiographic method and their defects are also determined.

[3].A.M.Torbati, R.M.Miranda, L.Quintino and S.Williams has optimized a combination of current Intensity, welding speed, electrode angle and shielding gas parameters for better penetration and free from inner layer defects of duplex steel joints by Gas tungsten arc welding (GTAW).

[4].Jose Maria Gomez de Salazar, Alicia Soria and Maria Isabel Barrena has determined the optimal content of N_2 in the shield gas for MIG welding of duplex steel by examining their microstructure and mechanical properties.

[5].R.B.Bhatt, H.S.Kamat, S.K.Ghosal and P.K.De has investigated how the effect of nitrogen addition in shield gas of gas tungsten arc welding(GTAW) of Duplex steel and how it alters the micro structure properties like austenite-ferrite ratio and distribution of alloying elements were studied.

[6].P. Sathiya, S.Aravindan, R.Soundararajan and A. Noorul Haq has investigated the effect of shielding gases in gas tungsten arc welding on mechanical and metallaurgical properties of Duplex Stainless Steel.

[7].Jing Wang, Min-xu Lu, Lei Zhang, Wei Chang, Li-ning Xu, and Li-hug Hu has compared the processes of Metal Inert Gas (MIG) welding and Tungsten Inert Gas (TIG) welding for duplex stainless steel (DSS) and low alloy steel.

[8].Huei-Sen Wang has investigated the influence of welding variables -wire feeding techniques, wire feeding rates and heat inputs on the cooling rate and heat affected zone (HAZ) areas of multi-pass weldments in a super duplex stainless steel. Microstructure analysis is done for the same.

[9].Tsann-Shyi Chern, Kuang-Hung Tseng, Hsien-Lung Tsai has investigated the effects of the specific fluxes used in the tungsten inert gas(TIG) process on surface appearance, weld morphology, angular distortion, mechanical properties, and microstructures when welding 6 mm thick duplex stainless steel.

[10].Dong Min, Jun Shen, Shiqiang Lai, Jie Chen has investigated the effects of heat input on the microstructures and mechanical properties of Tungsten inert gas.

[11].Emel Taban has explained plasma arc welding of duplex stainless steel depending on the heat inputs of the joints and relation between heat input and properties of weld.

[12].M.Yousefieh, M.Shamanian and A.Saatchi has used Taguchi method to optimize gas tungsten arc welding parameters of duplex stainless steel welds and it was found that the pulse current was the most influencing factor for welding.

3. Material

Duplex steels are of two-phase microstructure (hence the name “duplex”), containing both austenite and ferrite. Because of such specific microstructure, duplex steels combine to a certain extent the advantages of two different sides. On one side, there are the ferritic and martensitic chromium-steels. Due to their Cr-contents of 18% and higher, they provide relatively high toughness as well as very good resistance against stress-corrosion-cracking in chloride-containing agents. Alloy 2205 is a 22% Chromium, 3% Molybdenum, 5-6% Nickel, nitrogen alloyed duplex stainless steel with high general, localized and stress corrosion resistance properties in addition to high strength and excellent impact toughness. Alloy 2205 provides pitting and crevice corrosion resistance superior to 316L or 317L austenitic stainless steels in almost all corrosive media. It also has high corrosion and erosion fatigue properties as well as lower thermal expansion and higher thermal conductivity than austenitic. The yield strength is about twice that of austenitic stainless steels.

Table 1: Chemical Composition of S2205 Duplex Stainless Steel

S2205	C	Mn	Si	P
Wt %	0-0.03	2	1	0- 0.03
S2205	S	Cr	Mo	Ni
Wt %	0-0.02	21-23	2.3-3.5	4.5-6.5

Electrode used in both Gas Tungsten Arc Welding and Plasma Arc Welding was 2% Thoriated Tungsten Electrode. Shielding gas used in Gas Tungsten Arc Welding was argon. Plasma gas used in Plasma Arc Welding was argon and shielding gas was argon+2-5% hydrogen. AVESTA 2209 is used as a filler rod for both process.

4. Experimental Procedure

4.1 Gas Tungsten arc welding

There are many factors that influence the quality of weld obtained, out of which the prominent ones are selected for the experiment. They are**:**

i. Voltage
ii. Current
iii. Electrode diameter
iv. Shielding Gas flow rate.

Table 2: Input Parameters for Gas Tungsten Arc Welding

Voltage (V)	Current (A)	Electrode diameter (mm)	Shielding gas flow rate (psi)
16	160	1.6	16
18	180	2.4	18
20	200	3.2	20

We do optimization of process parameters for achieving better weld quality and cost effectiveness. Taguchi methods are used to provide optimized designs. One such design is orthogonal array which helps is studying the whole range of parameters with few experiments.
Formation of Orthogonal Array by Taguchi Method:
No. of parameters: 4
No. of level: 3
Selection of array: L9 (3 * 3) orthogonal array
Here 'L' signifies the No. of levels and
'9' signifies the No. of runs.
Thus L9 array has 9 runs.
A L9 array can be used to cover all combination of two parameters at three levels each.

Table 3: Combination of Values Obtained from L9 Orthogonal Array for Gas Tungsten Arc Welding

Voltage(V)	Current(A)	Electrode diameter (mm)	Shielding gas flow rate(psi)
16	160	1.6	16
16	180	2.4	18
16	200	3.2	20
18	160	2.4	20
18	180	3.2	16
18	200	1.6	18
20	160	3.2	18
20	180	1.6	20
20	200	2.4	16

4.2 Plasma Arc Welding

There are many factors that influence the quality of weld obtained, out of which the prominent ones are selected for the experiment. They are:

- Current,
- Electrode diameter
- Plasma Gas flow rate

Table 4: Input Parameters for Plasma Arc Welding

Current(A)	Plasma gas flow rate (l/min)	Electrode diameter (mm)
130	0.8	1.6
140	1.0	2.4
150	1.2	3.2

Formation of Orthogonal Array by Taguchi Method:
No. of parameters: 3
No. of level: 3
Selection of array: L9 (3*3) orthogonal array
Here 'L' signifies the No. of levels and
'9' signifies the No. of runs.
Thus L9 array has 9 runs.
A L9 array can be used to cover all combination of two parameters at three levels each.

Table 5: The combination of values obtained from L9 orthogonal array for Plasma Arc Welding

Current(A)	Plasma Gas flow rate (l/min)	Electrode Diameter(mm)
130	0.8	1.6
130	1.0	2.4
130	1.2	3.2
140	0.8	2.4
140	1.0	3.2
140	1.2	1.6
150	0.8	3.2
150	1.0	1.6
150	1.2	2.4

5. Microstructure

5.1 Plasma Arc Welded Sample

The figure 1 shows the Base metal region of Plasma Arc Welded Duplex Stainless Steel. The austenite grains are elongated along the direction of rolling or forming. The ferrite gives hardness, stress corrosion cracking and the austenite gives corrosion resistance and ductility.

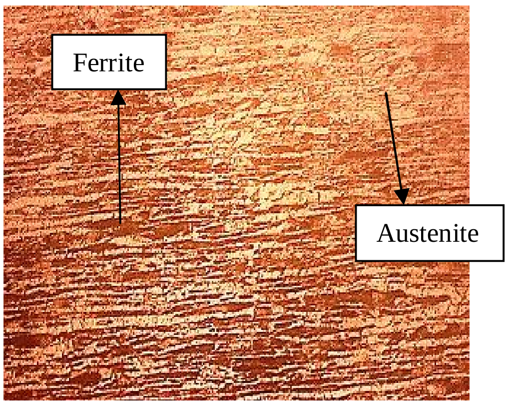

Fig. 1 Base Metal Region

The figure 2 shows the heat affected zone of Plasma Welded Sample where rapid cooling leads to irregular grains of ferrite and austenite. The presence of austenite is lesser compared to ferrite.

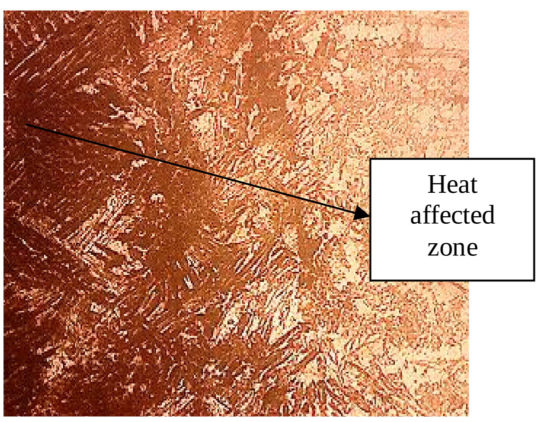

Fig. 2 Heat Affected Zone

The figure 3 shows the plasma welded region of the metal with large dendrites of austenite with partial ferrite. Here the austenite presence is higher than what it is observed in Heat Affected Zone and Parent Metal Region.

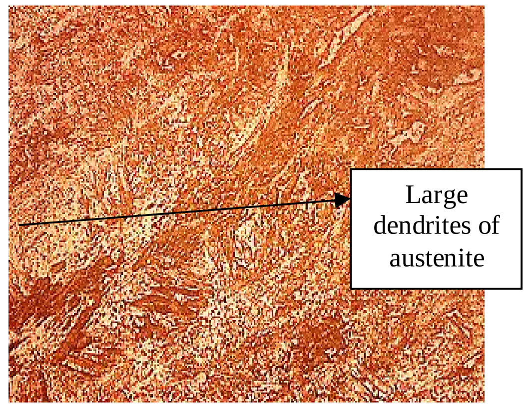

Fig. 3 Weld Zone

5.2 Gas Tungsten Arc Welded Sample

The figure 4 shows the Base metal region of Gas Tungsten Arc Welded Duplex Stainless Steel.

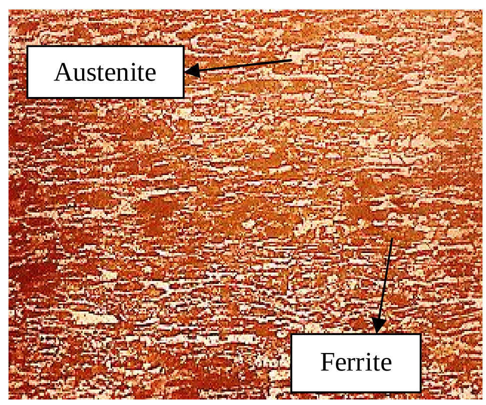

Fig. 4 Base Metal Region

The figure 5 shows Gas Tungsten Arc welded region of the metal with large dendrites of ferrite. Due to the lack of austenite content and slightly better ferrite content the hardness of this region is high

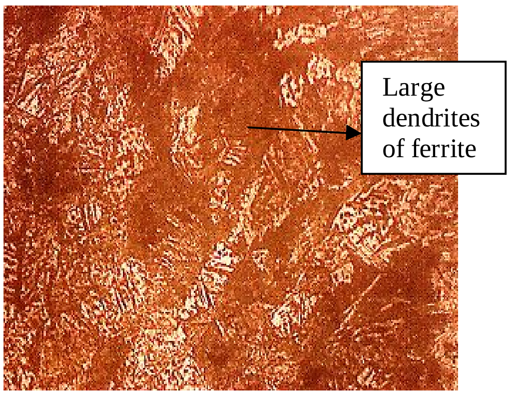

Fig. 5 Weld Zone

The figure 6 shows the heat affected zone of the weld where the base metal due to stress and heat changed its direction. In the heat affected zone the lack of austenitic content results in higher hardness when compared to the base metal but it is lesser than Weld Zone.

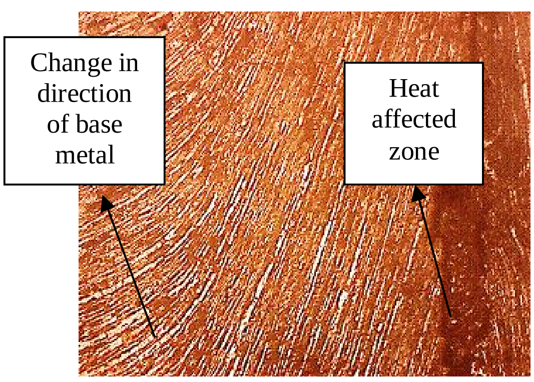

Fig. 6 Heat Affected Zone

6. Vickers Microhardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

$HV=1.854F/d^2$

where,F=load kgf ,

d=arithmetic mean of two diagonals d_1 and d_2 in mm

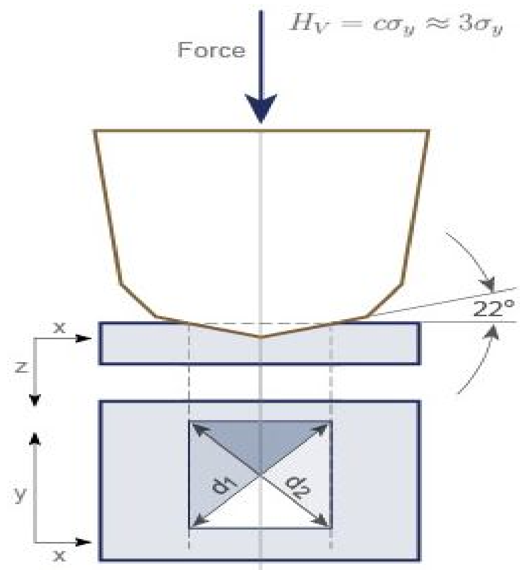

Fig. 7 Vickers Hardness Test

Table 6: Vickers Hardness Test Result for Plasma Arc Welded Sample at 0.5 kg Load

SAMPLE	BASE METAL (VHN)	WELD ZONE (VHN)	HEAT AFFECTED ZONE (VHN)
P1	274.6	254.5	275.0
P2	271.2	250.2	271.8
P3	267.3	246.0	268.8
P4	289.8	269.0	290.4
P5	286.0	265.7	287.2
P6	282.7	261.4	284.0
P7	297.3	277.0	299.3
P8	294.0	274.2	295.8
P9	291.6	270.6	282.8

Table 7: Vickers Hardness Test Result for Gas Tungsten Arc Welded Sample at 0.5 kg Load

SAMPLE	BASE METAL (VHN)	WELD ZONE (VHN)	HEAT AFFECTED ZONE (VHN)
T1	328.4	403.8	334.1
T2	324.4	399.0	329.0
T3	326.8	394.0	326.2
T4	324.1	396.8	328.4
T5	319.2	392.1	324.2
T6	315.1	387.5	319.8
T7	321.0	394.4	326.6
T8	314.8	387.0	319.2
T9	308.5	381.5	313.1

From above Test for Gas Tungsten Arc Welded Sample it is observed that the hardness value increases as we move from base metal region to the welded zone region across the heat affected zone. Hardness was high in the weld region than Base Metal and Heat affected zone. Micro hardness Test of Gas Tungsten Arc Welded Duplex stainless steel shows that hardness was in the order of Weld Zone>Heat Affected Zone>Base Metal, where as for Plasma arc welding the order was Heat Affected Zone>Base Metal>Weld Zone. Hardness in weld region for Gas Tungsten Arc Welded Sample was higher than Plasma arc welded sample.

7. Bend Test

Bend tests are generally used in the weld to know the quality of weld. The bend tests are conducted to evaluate the ductility and soundness of welded joints. Also to detect major defects like incomplete fusion, cracking and macro defects of welded joints. The quality of welds can be evaluated as a function of ductility to resist cracking during bending. The specimens for the bend test are of 60 mm long with 8 mm thickness. Both Tungsten weld and Plasma arc weld samples are taken and bend test is conducted. The specimen has been bended to 180 for conducting bend test. The bend test conducted specimens should are examined 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.

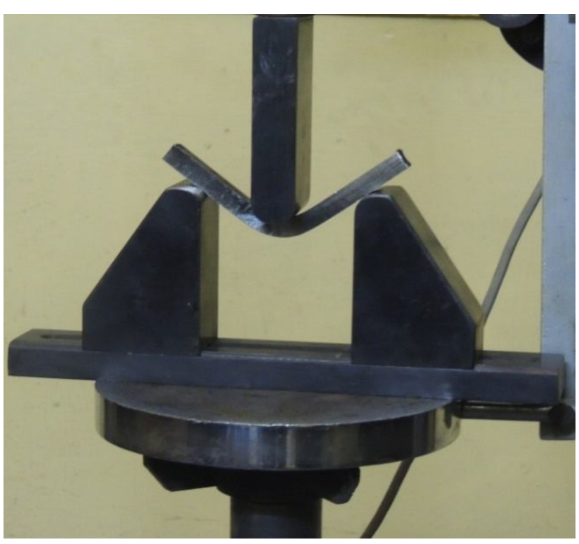

Fig. 8 Bend Test

Table 8: Bend Test Result for Plasma Arc Welded Samples

SAMPLE	ANGLE OF BENDING	REPORT
P1	180	No Fracture
P2	180	No Fracture

Table 9: Bend Test Result for Gas Tungsten Arc Welded Samples

SAMPLE	ANGLE OF BENDING	REPORT
T1	180	Fracture
T2	180	Fracture

The bend test results in fracture in case of Gas Tungsten Arc weld sample and a perfect 180 angle bend in case of plasma arc weld sample. The reason for this is due to the presence of higher ferrite content and lower austenite content in Gas Tungsten Arc sample and vice versa in case of Plasma weld sample.This proves that Plasma weld samples show good ductility in the weld zone when compared to Gas Tungsten Arc weld sample.

8. Radiographic Testing

Radiographic Testing (RT), or industrial radiography, is a nondestructive testing (NDT) method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The beam of radiation must be directed to the middle of the section under examination and must be normal to the material surface at that point, except in special techniques where known defects are best revealed by a different alignment of the beam. The specimen to be inspected is placed between the source of radiation and the detecting device, usually the film in a light tight holder and the radiation is allowed to penetrate the part for the required length of time to be adequately recorded.

Table 10: Radiography Test Description

Material	Duplex Stainless steel
Thickness	8 mm
Source	X-Ray KV:140 MA:5
Exposure Time	3 Minutes
Density	2.2 to 2.6
Source to film distance	30 inch
Dev Time	4 minutes
Dev Temp	22^0c
Technique	Single Walled Single Image(SWSI)
Sensitivity	2T
Type of film	Agfa D7
Specification	ASME Sec V,VIII

The radiographic examination revealed that major defect in Gas Tungsten Arc Welded Sample was Lack of Penetration where as in Plasma Arc Welded Sample no major defect was found.

9. Conclusion

i. It is observed that the Vickers hardness value in the welded zone of Gas Tungsten Arc welded sample is greater than that of the Plasma welded sample.

ii. Gas Tungsten Arc Welded sample had higher Vickers hardness in weld region compared to base metal and Heat Affected Zone. Hardness was in order of Weld Zone>Heat Affected Zone>Base Metal. Plasma Arc Welded sample had higher Vickers hardness in Heat Affected Zone compared to weld region and base metal region. Hardness was in order of Heat Affected Zone>Base Metal>Weld Zone.

iii. Bending tests suggest that there was breakage in case of Gas Tungsten Arc welded sample whereas in Plasma Arc welded sample no breakage occurred.

iv. The non destructive radiographic testing shows the major defect present in Gas Tungsten Arc welded samples is Lack of Penetration where as for Plasma Arc welded samples had no major defects.

v. The microstructure examination of the plasma welded sample showed that weld region had large dendrites of austenite with partial ferrite and for TIG welded sample reveals that weld region had large dendrites of ferrite and lack of austenite.

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