Experimental Investigation of DSS/HRS GTAW Weldments

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Abstract

Objectives: The Gas Tungsten Arc Welding (GTAW) of blanks 2 mm thick of Duplex Stainless Steel (DSS) and Hot Rolled Medium and High Tensile Structural Steel (HRS) is carried out to investigate the metallurgical, mechanical properties and the fracture. **Methods**: The characterization of the weldments involves tests, viz. macrostructure, microstructure, micro composition analysis through Energy Dispersive Analysis of X ray (EDAX) to find out the metallurgical properties and micro hardness test, tensile test, bend test to determine the mechanical properties of the weldments. Topography of tensile test fractured specimens was analyzed with the help of Scanning Electron Microscope (SEM) and determines the influence of the welding on the ductility of the weld material. **Findings**: The increase in the weld zone micro hardness and formation of dendritic delta ferrite microstructure, when compared with the DSS parent metal having elongated grained austenite with ferrite and the HRS parent metal having fine grains of ferrite, caused the joint efficiency of the DSS/HRS weldment to increase. The Energy Dispersive Analysis of X ray (EDAX) indicates the formation of dendritic delta ferrite microstructure is attributed to the presence of elements like Si and Cr. The SEM fractography analysis indicates that the weldments possess good tensile strength without decrease in ductility of the fusion zone. **Applications**: Experimental investigation of mechanical properties and microstructure of DSS-HRS dissimilar GTAW weld joints and fracture analysis with EDAX to identify the changes in the chemical compositions of the fractured specimen.

Keywords: Duplex Stainless Steel, GTAW, Hot Rolled Steel, Mechanical Properties, Microstructure

1. Introduction

The Duplex Stainless Steel (DSS) comprises of both ferritic and austenitic microstructures. By virtue of its high chromium and nitrogen content it possesses good resistance against pitting and stress corrosion cracking. In spite of its chemical immunity, it is prone to formation of sigma phase an inter metallic phase ranging temperature from 320 to 955°C. Further the ferrite microstructure decomposes leading to embrittlement at around 475°C. Hence the DSS is avoided in the temperature range of

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above 250 to 325°C, since the embrittlement shall cause around 50% reduction in the impact toughness. The formation of inter metallic phase is influenced by the elemental composition and thermal/thermo mechanical process undergone by the material. The heat treatment involving slow cooling makes the material vulnerable to the formation of detrimental inters metallic phases. The metallurgy of DSS comprises of carbon, nitrogen, chromium, nickel, molybdenum and other alloying elements like manganese, copper, tungsten, silicon, selenium, phosphorus, sulphur, titanium, etc¹. The chromium, silicon, molybdenum, tungsten, titanium and niobium favor the ferritic microstructure and called as fertilizers. The carbon, nickel, manganese, nitrogen and copper are austenitisers. The DSS has good weld ability. Generally the heat-affected zone of DSS welded joints have high austenite content and hence offers good resistance to localized corrosion. The precautions taken for obtaining good quality welds are avoiding preheating, allowing to cool to below 150°C between weld passes, the heat treatment with minimal temperature increase of 30°C to 50°C to achieve full dissolution of inter metallic phase in the weldment²⁻⁹. The DSS material is used in fabricating equipment and machine components used in pulp and paper industry, desalination plants, pressure vessels, heat exchangers due to its high mechanical strength, fatigue resistance, very good resistance to corrosion, low thermal expansion and good weld ability. The Hot Rolled Steel (HRS) is used in fabrication of railway and automotive bodies due to their good weld ability. The Hot Rolled Steel (HRS) contains carbon and manganese which ensures good weld ability. The HRS is strengthened by micro alloying with elements like niobium, vanadium and titanium separately as required in order to achieve high strength to weight ratio, better formability, weld ability and toughness 10-16. In this paper an effort is made to explore the feasibility of fabricating dissimilar welding of DSS/HRS, due to the current trend of using Stainless steel in the railway coach bodies due to their aesthetic appeal and durability¹⁷.

2. Material and Methods

The experimental setup comprised of, TRIDENT 4009 model GTAW machine with 2 % thoriated tungsten electrode and manual welding technique with a root gap of 1.2 mm. In this experiment square butt welding joint method in the sheets of size 150 mmx250 mm followed by using Gas Tungsten Arc Welding (GTAW) process. The weldments were fabricated with butt joint configuration using E 309LT-1 electrode as filler metal. The welding process parameters used were 16V, 55 Ampere. Suitable fixtures and argon shielding was provided to obtain defect free joints.

2.1 Material

The 2 mm thick blanks of Duplex Stainless Steel (DSS) and Hot Rolled Medium and High Tensile Structural Steel (HRS) plates conforming to AISI 2205 and IS 2062:2011

standards were used for carrying out the experiments. Chemical compositions of Duplex stainless steel, Hot rolled steel and filler rod conforming to grade 309 were shown in the Table 1.

Material	DSS	HRS	Electrode
С	0.022	0.23	0.035
Cr	22.54	-	23.45
Ni	4.899	-	12.6
Мо	3.113	-	-
Si	0.331	0.4	0.53
Р	0.02	0.045	0.024
S	0.011	0.045	0.021
Mn	1.023	1.5	1.58
Cu	0.089	-	-
N	-	0.012	-
Al	0.008	0.02	-
Ti	0.01	-	-
W	0.037	-	-
Fe	67.889	97.748	61.76

Table1. Chemical Composition of base metals andelectrode by % weight

2.2. Method

DUKON WILSONTESTER device was used to find out the Vickers hardness measurement and the specimens preparation were done based on the standards ASTM E340-2000(RA 2006) and ASTM E407-2007.The ductility of the weldments was ensured through the bend test, which showed no development of crack and hence the weldments were found satisfactory.

2.2.1 Micro Hardness Test

Vickers hardness measurement was carried out as per ISO 6507: 1997 standards with 1 kg load. Measurement of Hardness values of 3 consecutive readings taken on parent metal, HAZ and weldment portion as shown in Figure 1.

The Figure 1 explains about hardness values decreasing trend from weld metal to HAZ and HAZ to DSS base metal area. It gives indication that the hardness value in DSS base metal, HAZ is low as compared to weldment area. Correspondingly hardness value shows increasing trend from DSS base metal to weld metal through DSS HAZ and also HRS base metal to weldment through HRS HAZ. It gives the indication that hardness value in weld metal is high compared to HRS HAZ and HRS base metal. The hardness value in this experiment shows that the strength of the weld metal, DSS base metal and DSS HAZ is high compared to HRS HAZ and HRS base metal portion.



Figure1. Micro Hardness values of DSS/HRS weldment

2.2.2 Metallurgical Test

The metallurgical investigations were carried out by following standard metallurgical procedure. Microstructure was analyzed through optical microscopy with a magnification of 250x to analyze the micro structure of the weld zone, HAZ and both DSS/HRS base metals. The macro structural analysis was done using Glycergia reagent as etchant to assess the welding integrity in the fusion zone, penetration and the weld bead shape with 10x magnification. The macro analysis of the DSS/HRS specimen exposed total weld fusion with no defects and is shown in Figure 2.



Figure 2. Macro structure of DSS/HRS Weldment

The micro structural analysis was done using 10 % NaOH etchant solution as reagent. The micro examination of the DSS parent region revealed elongated grains of austenite (white) with ferrite (Brown). The microstructure of DSS is free from sigma, inter metallic phases & other precipitates as shown in Figure 3. The micro examination of the HRS Parent metal region revealed fine grains of ferrite present in the matrix as shown in Figure 4. The microstructure of HAZ DSS revealed that dendrite grains of austenite with ferrite as shown Figure 5. Also, micro examination of the HRS HAZ reveals acicular grains of ferrite with pearlite as shown in Figure 6. The micro examination of the weld region (fusion zone) revealed dendrite delta ferrite as shown Figure 7.



Figure 3. DSS parent metal



Figure 4. HRS parent metal



Figure 5. DSS HAZ



Figure 6. HRS HAZ



Figure 7. Fusion Zone

2.2.3 Tensile Test

The tensile tests with loading rate of 0.5 mm/min were carried out by using INSTRON 1195 model tensile testing machine. The tensile test was conducted to determine the tensile properties namely ultimate tensile strength, yield strength, percentage of elongation and reduction of cross sectional area at room temperature. The specimens were prepared according to ASTM E8-04. Tensile test was conducted by using Ultimate Tensile Testing Machine with test specimen of DSS/HRS to evaluate the tensile strength of the weld as shown in Figure 8(a). Fracture occurred at the HRS side based on the UTM results as shown in Figure 8(b).



Figure 8. DSS/HRS Tensile Specimen (a) Before testing (b) After testing

The above mentioned observation shows that the strength of the weldment fusion zone is more robust compared with DSS/ HRS base metal. Tensile test values for the dissimilar metal joint given in Table 2. Ultimate tensile strength (340 Kgf/mm²) is high as compared to yield strength (240 kgf/mm²). This indicates that the mechanical properties of DSS/HRS dissimilar weld metal joints are able to meet the required mechanical properties.

Table2. Tens	sile test values	-DSS/HRS join	ıt
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Observation	Actual
Yield Strength (Kgf/mm ²)	240
Ultimate Tensile strength(Kgf/mm ²)	340
% Elongation in 50mm GL	22.43
Fracture Location	HRS

2.2.4. Fractography Analysis

The tensile test fractured weldments were subjected to fractographic analysis through Scanning Electron Microscope (SEM). Image from the fractured region of weldment was taken from the SEM equipment and the magnified view shown in the right hand side top corner of the Figure 9 indicating a ductile fracture. Micro level cup and cone form of fracture observed due to presence of dimples.



Figure 9. Scanning Electron Microscope image of fractured DSS/HRS Tensile Specimen

The EDAX facility attached with the SEM equipment was used to carry out the micro elemental analysis. The EDAX test report as shown in Figure 10 reveals Cr depletion, indicating the reason for the failure in the heat affected zone of HRS



Figure 10. EDAX micro elemental analysis of DSS/HRS Fusion Zone

3. Results and Discussion

The micro hardness analysis indicates an increase in the hardness of the fusion zone, when compared to the DSS (parent metal and heat affected zone) and HRS (parent metal and heat affected zone). The increase of hardness in the fusion zone can be qualified to the formation of dendrite delta ferrite microstructure and the presence of Si and Cr in the fusion zone; which is revealed in the micro elemental analysis results obtained from EDAX

test. Hardness increase in the fusion zone has considerably improved the tensile strength of the weldment. The fine ferrite grains of HRS parent metal and the acicular grains of ferrite with pearlite in HRS heat affected zone; combined with the formation of Cr depletion zone in the HRS - HAZ has caused the failure to take place in the HRS-PM/HAZ during the tensile test. The GTAW welding with root and cap run (multi pass) welding and by virtue of the excess heat input given by the GTAW process causes the softening of the heat affected zone due to the annealing effect/soaking in the excess heat. This phenomenon shall have led to the failure in the heat affected zone. The weldment in spite of its high hardness has not formed crack during the bend test, due to the absence of inter metallic phases and detrimental sigma phase and precipitates.

4. Conclusion

The DSS/HRS dissimilar welding using GTAW technique has proved to yield good quality weldments without any undesirable metallurgical changes and possessing good mechanical properties. This experimental work shows that the DSS/HRS could be welded even in 2 mm thick plates, which is much desirable and has scope of application in offshore chemical sector. The composition and microstructure of DSS/HRS are compatible for welding and the good improvement in the tensile strength could be achieved.

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