A REVIEW ON MECHANICAL PROPERTIES OF DUPLEX STAINLESS STEEL

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ABSTRACT

A review is made on tests conducted on specimens of Duplex stainless steel. The review focuses light on study of sensitization and corrosion by the different authors for governing sensitization and corrosion in duplex stainless steel by using different welding processes. Besides the difficult of little ductility and low hardiness of duplex stainless steel, welds due to the microstructure features of the weld division as a outcome of weld heat contribution rate and heat transfer rate feature, susceptibility to intergranulated corrosion triggered by the reduction of the chromium content of the weld atmospheremainly in the HAZ is a most important concern.Controlling the completedistribution of the material in convinced engineering application irrespective of its beautiful economics shared with reasonable strength and brilliant corrosion features of AISI 409 M. Duplex stainless steel throughout welding (TIG,MIG, and SMAW) has explored. Its sensitization and corrosion was able to be evaluated by chemical experience of the weld cross segment. Then the features of sensitization and corrosion can be studiedby Scanning Electron Microscope. This review settled that difference in heat involvement resulted in significantvariations in the mechanical properties of the weld which marks on the sensitization and corrosion.

Keywords-Duplex stainless steel, corrosion, mechanical properties, Sensitization, tensile test.

1. Introduction

Stainless steels are alloys of iron having at least 11% chromium by weight. They show superior corrosion resistance related to other steels mainly due to the inactive film of chromium oxide which forms on the surface. However, in order for a stainless steel to maintain its stainless-ness in destructivechemical environments, more amounts of chromium must be added to the alloy (Lippold and Kotecki 2005) [1]. In adding to chromium, other alloying elements such as nickel, molybdenum, manganese, nitrogen etc. are correspondingly added in order to deliver better opposition to different methods of corrosion. Several alloying elements arealso added to improve mechanical properties and weld ability without negotiating on the corrosion resistance (Ki Leuk Lai *et al.* 2012) [3]. Stainless steels can be categorized into five groups based on their microstructures: Duplex, Austenitic, Martensitic, Duplex and Precipitation Hardening stainless steels (Davis1994) [5].

Duplex stainless steels (DSS) have a microstructure containing of ferrite and austenite in approximately equal amounts and showimproved corrosion resistance and mechanical properties in relationship to single phase stainless steels (Kazior*et al.* 2004) [7]. They deliversuperb resistance to pitting corrosion and stress corrosioncracking even in chloride situations (Singh Raman and Siew 2010) [9]. DSS can be categorized into three groups based on their pitting resistance equivalent numbers (PRE_N). They are: lean duplex alloys having a PRE_N slightly greater than that of austeniticstainless-steelgrades andhaveup to20wt%Crand Mo**.**

Standard duplex alloys with proximate 22 wt% Cr and 3 wt% Mo, having a PRE_N lying between 33 and 36, and, super duplex alloys with more than 25 wt% Cr, 3.5 wt% Mo and 0.2-0.3 wt% N, with a PRE_N greater than 40.

Newly, special grades so-called hyper duplex stainless steels with greatly higher chromium and nitrogen levels has established (Alvarez-Armas and Degallaix-Moreuil 2009) [11]. DSS found claims in various industries which comprise hostile environments and like chemical and petrochemical, oil and gas, pulp and paper, power generation, hydrometallurgy, marine transportation, construction etc. which consist of hostile environments (Gunn 1997) [13]. A foremost limiting factor in the applicability of DSS is their exposure to various intermetallic phaseswhen they are exposed to higher temperatures for smaller duration. The sigma phase is the main phase forming when they are exposed to temperature range of 600-800°C for shorter periods. This sigma phaseintensely affects the tensile properties.

2. Literature review

M.O.H. Amuda [2] investigated the effects by making the welds on a 1.5mm thick plate of 16 wt% Cr DSS conforming to AISI 430 commercial grade , using TIG torch in argon atmosphere at a heat flux among 1008W to 1584W and speed among 2.5mm/s and 3.5mm/s and concluded that:

i) The width of the sensitization zone increases when there is increase the heat input. The depth of the sensitization zone in the thickness direction is irrelevant and it is usually within one half of a millimetre.

ii) The use of heat input more than 432J/mm rises the expansion of sensitized regions. The level of heat input matches to heat fluxes in the series 1008-1296W and welding speed among 3mm/s and 3.5mm/s. Under this state the regular cooling time is about 10s.

Du Toit M [4] investigated the susceptibility of 12% chromium type 1.4003 duplex stainless steel to heat affected zone sensitization and intergranular stress corrosion cracking and concluded that sensitization may lead to intergranulated pitting and stress corrosion cracking inside the heat -affected zone on contact to a corrosive atmosphere. Four distinct modes were identified:

Mode 1: Sensitization of martensitein the heat-affected zone of the welds placed onincorrectly annealed parental metal through a dual-phase ferrite-martensite microstructure.

Mode 2: Sensitization of martensite when multiple welds are deposited in such a way that the heat-affected zone of the 2nd pass overlaps the heat-affected zone of the 1^{st} pass.

Mode 3: Sensitization of d-ferrite within the high temperature heat-affected zone during rapid cooling after welding at very low heat input levels.

Mode 4: Sensitization of austenite in the high temperature heat-affected zone during very deliberate cooling after welding at extremely high heat input levels.

Also he resolved that Titanium-stabilized grades of 1.4003 are mostly not susceptible to Mode 1, Mode 2or Mode 4 sensitization, but may be susceptible to Mode 3 sensitization if the austenite potential is low.

M.L.Greeef [6] investigated the susceptibility of 11-12% chromium type EN 1.4003 duplex stainless steel to sensitization during continuous cooling after welding at low heat input levels. It concluded that sensitization of type En 1.4003 duplex stainless steel during continuous cooling after welding is possible if low heat input levels are used. Welding bysmall heat inputs can destroy the conversion of ferrite to austenite as the heat affected zone cools concluded the (austenite+ferrite) dual phase region during welding. This results in largely duplex high-temperature heat affected zones. With an increase in heat input, the cooling rate after welding is reduced, andmore austenite forms in the high-temperature heat affected zones. Sensitization is prohibited by the existence of plenty austenite to exclude continuous ferrite-ferrite grain boundaries.

Bipin Kumar Srivastav,S.P. Tewari [8]studied the effect of arc welding parameters on quality of welds and concluded that several process control parameters in SAW influence bead geometry, microstructure as well as weld chemistry .Their combined effect is reflected on the mechanical properties of the weld in terms of the weld quality as well as joint performance . The selection of appropriateprocedureparameters are primary means by which suitable heat affected zone properties ,optimized bead geometry,lowestremaining stresses are made. The mechanical properties of the weld are influenced by the composition of the base metal and to a large extent by the weld bead geometry and shape relationship as well. It observed with rise in electrode stick out, hardness of the weldmentrises, yield strength and impact value decreases, ultimate tensile strength of the joint initially decreases but thenrises provided welding current and voltage arc kept at a constant level. Purpose of the flux constituents like CaO, MgO, CaF_2 and Al_2O_3 in submerged arc welding considered and resolved that among the flux ingredients, MgO appears to be significant on its own in influencing the mechanical properties.

M.O.H.Amuda and S.Mridha [10] studied and analyzed the sensitization problem in duplex stainless steel welds as well as remediation techniques. Severalmechanisms have been explored to explain the dynamics of sensitization, but the chromium depletion has been only one proved experimentally. Sensitization is measuredby different initiatives reaching from control of interstitial elements (C+N) to level typically less than 0.03 wt % over ensuring greater austenite potential and use of dual stabilization involve mainly Titanium and Niobium to the control of weld heat input in the range 0.5-1.5kJ/mm.

E. Bayraktar, D.Kalpan [12] analyzed the characterisation of base metal and welded parts by hardness, Erichsen and impact tensile tests (ITT) of Duplex Stainless steel based on the TIG and detected that transition temperature and deep drawability can used for estimating of welding circumstances and also the material features.

C.J.VanNiekerk, M.Toit [12] tested two plates of 2 and 4 mm for sensitization characteristics of AISI 409 titanium stabilized duplex stainless steel during low heat input welding and concluded that for a plate thickness

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of 2mm, sensitization occurs for heat input of 0.1 to above 0.25 kJ/mm, and for 4mm plate thickness in the 0.2 to 0.9 kJ/mm heat input range. Due to faster cooling rate of thicker sections the 4 mm steel experienced sensitization over a much larger heat input range than the 2mm steel. TiN is stable at temperature below 1500°C,therefore there is a decrease in the availability of Ti to form TiC and increased $M^{23}C^{6}$precipitation.

K.Shamugam, A.K. Lakshminarayan and V. Balasubramania [14]studied the effect of filler metals such as austenitic stainlesssteel, ferritc stainless steel and duplex stainless steel on tensile and impact properties of the duplex stainless steel conforming. AISI 409M grade and resolved that links fabricated by duplex stainless steel filler metal presentedadvanced tensile strength and hardness related to the links fabricated by austenitic and FSS filler metals. Joints fabricated by austenitic stainless steel filler metals exhibited higher ductility and impact toughness compared with the joints fabricated by duplex stainless steel filler metals.

E. Bayraktar, D. Katundi [15]conducted testing on a special crash test device in different temperature and the simulated crash test were performed at a constant speed of 5.52m/s and concluded that according to the testing temperature, fracture mode varies. At a low temperature, brittle fracture occurs while at a high temperature ductile fracture occurs.

EslamRanjbamode [16] worked on microstructuralfeatures of the tungsten inert gas (TIG) welded in AISI 409 duplex stainless steel and consequence of the welding parameters on grain size local miss-alignment and low angle grain boundaries was inspected. It resolved that welding plastic strain is increasing factor for local miss-orientation and low angle grain boundaries. It displays that the final state of strain is the result of the competition between welding plastic strains and stress relieving from recrystallization.

hmed Khalid Hussain [17**]** studied the influence of welding speed on tensilestrength on welded joints in GTAW process of aluminium alloys. Experiments wasperformed on specimen of single V butt joint having different bevel angles and bevel heights. The experimental results demonstrate depth of penetration of weld bead decreases with increase in a bevel height. The tensile strength increased with lower weld speed and decreasing heat input rate. It was found bevel angle of the weld joint have profound effect on the tensile strength.

E.TABAN [18] investigated the microstructural and toughness properties and mechanical properties of the gas metal arc welded 6 mm thick modified X2CrNi12 SS with two different heat input and resolved that grain size haveforemost effect on impact toughness. Grain coarsening has no adverse influence either on tensile properties or on a bend properties but the heat affected zone impact toughness for sub-zero temperature generally decreases and this depends on amount of grain coarsened microstructure and eventual precipitates present.

J. Rawlings [19] investigate the effect of service temperature on the mechanical properties of several duplex P/M stainless steel grades including 410L.409 Cb and concluded that the elevated temperature tensile properties of these duplex P/M alloys were excellent and in most cases actually exceeded results published for wrought materials.

Reza Atefi [20] tested different chemical composition in order to highlight the influence of stabilizing elements on microstructure as the existing filler wires leads to oxidation problem and / orthermal fatigue strength that drastically 266 reduces assembly lifetime and revealed the major influence of titanium on the grain refinement in the molten zone. Theleast Ti content 0.45 wt% in filler wire is required to be efficient as a grain refiner.

YunanPrawoto [21] calculatedcorrosion rates and pitting morphology of chosen duplex stainless steel and found, decreasing pH increases the corrosion rate. Similarly, increasing temperature increases corrosion rates this can be achieved well using different solutions with different temperature and periods of immersion.

M.O.H Amuda and S. Mridha [22] reports the microstructural features of FSS welds produced under different heat input rates along with the governing parameters of welding like travel speed, welding current and material properties and examined, regardless of the welding state, the primary solidification structure changed from a predominentelyduplex structure to a matrix interspersed with increasing fraction of inter dendritic martensite in weld metal, grain boundary martensitic in heat exaggerated zone. This implies that below the critical welding current value, the mechanical properties of duplex steel weld might be influenced by both welding current and speed.

M. Aksoy [23] studied onimpact of strong carbide establishing elements likeMo,Ti,V,Nb and homogenization on the adhesive wear resistance on the duplex stainless steel (18 wt.% Cr). The wear behaviour of the homogenized and unhomogenized samples was investigatedin a block-on-ring apparatus under the loads of 40, 60, and 80 N respectively and the best result has been found that from the samples containing V and Mo. In addingmodels which contain of M23C6 carbides in their microstructure without carbide forming elements, gave good wear resistance under the load of 40N.

V. Balasubramanian [24] investigated the effect of welding processes such as shielded metal arc welding, gas metal arc welding and gas tungsten arc welding on tensile and impact properties of the duplex stainless steel conforming to AISI 409M grade on a rolled plates of 4 mm thickness which was used as the base material for preparing single pass butt welded joints and concluded that gas tungsten arc welded joints of duplex stainless steel have superior tensile and impact properties compared with shielded metal arc and gas metal arc welded joints and this is mainly due to the presence of finer grains in fusion zone and heat affected zone.

A.K. Lakshminarayan ,K. Shanmugam [25] evaluated the tensile and impact properties, microhardness , microstructure, and fracture surface morphology of continuous current gas tungsten arc welding (CCGTAW), pulsed current gas tungsten arc welding (PCGTAW), and plasma arc welding (PAW) joints and investigated that the PAW joints of dss steel shows superior tensile and impact properties when compared with CCGTAW and PCGTAW joints and this is mainly due to lower heat input, finer fusion zone grain diameter, and higher fusion zone hardness.

D.C.Oliver [26] investigates the relative exterior corrosion resistance of three alloys- two duplex stainless steel (AISI Types 409 and 441) and an aluminized mild steel; resolved that the De-icing salts evidentlybeneficial effect on corrosion resistance and specified that primary external corrosion mechanism causingfailure at the cold end of the exhaust system in the presence of de-icing salts is pitting. The greater chromium type 441 alloy was far extra resistant than type 409.

K. Shamugam [27] evaluated the effect of filler metals such as austenitic stainless steel, duplex stainless steel and duplex stainless steel on fatigue crack growth behaviour of the gas tungsten arc welded duplex stainless steel joints and found that the fatigue crack initiation behaviour, fatigue crack propagation behaviour and fatigue life of duplex stainless steel joints fabricated using duplex stainless steel filler metal are superior compared to the joints fabricated using austenitic stainless steel and duplex stainless steel filler metals.

EmelTaban [28] examinedhybrid welding properties, of 12 mm thick improved 12% Cr duplex stainless steel obeying with EN 1.4003 and UNS S41003 steels with a carbon content of 0.01% to improve the weldability and concluded that i) Sound joints of modified 12 Cr duplex stainless steel could be obtained by means of hybrid welding in the meantime tensile and bend testing exhibited satisfactorily results. ii) In microstructural examination, some grain coarsening was determined mainly at the HTHAZ and fused metal atthe root weld metal produced by plasma arc welding without filler metal. iii) Coarse ferrite grains do not have any adverse effect on tensile nor on bend properties but they lead to relatively low impact toughness only for sub-zero temperature depending on the amount of grain coarsened microstructures.

A.M.Mayer [29] discuss the possibility the diffusion from the weld metal can increase the carbon or nitrogen content of the heat affected zone consequently stabilize grain boundary austenite and concluded, ferrite grain development in the heat-affected zones of welds in 3CR12 has a detrimental consequence on impact properties of the welded joint. Ferrite grain growth canreserved by increasing amount of grain boundary austenite in the heat-affected zone at large temperatures. By increasing carbon, nitrogen contents in heat-affected zone should act to stabilize grain boundary austenite. Therefore, decrease in ferrite grain growth should be observed in the heat affected zone of 3CR12 welds. A reduction in the ferrite grain size arises in heat-affected zones of welds in 3CR12 if the carbon or nitrogen content of the weld metal is increased.

Martin Nicholas, Van Warmelo [30] explored subject of sensitization onunstabilizedduplexmartensitic dual phase 11-14% Cr steel in some detail after a number of failures in service due to accelerated corrosion and concluded that sensitization could occur due to a number of different mechanisms which were dependant on the heat treatment, no of thermal cycles and phases present in the material. Allnoticed modes ofsensitization can be prevented by stabilisation with titanium or niobium and appropriate design of material composition to yield a suitably high ferrite factor.

3. Conclusions

1. Extreme welding speed can worsen sensitization during low heat input welding.
2. Welding conditions that promotes the formation of martensitic in the HAZ can be ideal for the prevention of sensitization.
3. Sensitization can be controlled using i) Control of interstitial elements ii) Control of ferrite factor ;iii)With the use of stabilisation techniques ; iv) Control of weld heat input and cooling rate.
4. Corrosion can be minimize by several methods such as i) Material and welding consumable selection, ii) Surface preparation; iii) Welding design ; iv)Welding practice v)Passivation treatment.
5. Variation in heat input resulted in significant changes in the mechanical properties of the weld.
6. Gas tungsten arc welded joints of duplex stainless steel have superior tensile and impact properties compared with shielded metal arc and gas metal arc welded joints.

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