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Analysis of Sensitization of Austenitic Stainless Steel By Different Welding Processes: A Review

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Abstract

This paper deals with the review of different literature. The review focuses on analysis the effect of sensitization on the metallurgical properties of austenitic stainless steel by different welding processes. Austenitic stainless steel with Chromium and Nickel as basic constituents. It has excellent corrosion resistance properties and very good weldability. Austenitic stainless steels have a tendency to form chromium depleted zones at the grain boundaries during welding and heat treatment, where chromium combines with available carbon in the vicinity of the grain boundaries, to produce an area depleted in chromium, and thus becomes susceptible to intergranular corrosion. Austenitic stainless steel during welding (GTAW, GMAW, and SMAW) have been investigated. This review concluded that variation in normalize temperature, time and heat input due to welding and heat treatment resulted in significant changes in the mechanical properties of the austenitic stainless steels and due to the effect of sensitization mechanical properties (yield strength, ultimate tensile strength, Young's modulus, percentage reduction, percentage elongation, hardness, Corrosion resistance) of the material will be changed.

Keywords: Mechanical Properties, Metallurgical properties, Sensitization.

Introduction

Austenitic stainless steel:

Austenitic stainless steels are used in the nuclear industry, pressure vessels, transpotation, chemical, medical industry due to their superior mechanical properties and corrosion resistance [1]. Austerritic stainless steel are nickel chromium alloys with face centered cubic crystal structure having chromium content more than 12 wt%. These steel exhibit good ductility, formability and better yield strength. Austenitic stainless steels are most commonly used due to its corrosion resistance and low temperature toughness (examples include transportation of liquefied natural gas) [2].

Sensitization (grain boundary depletion of chromium and precipitation of chromium carbide near or at the grain boundaries) of the weldments is one of the potential problems in the welding of ASS. Sensitization leads to degradation of corrosion resistance as well as the mechanical properties [3, 4].

Sensitization refers to the breakdown in corrosion resistance due to depletion of chromium by the formation, growth, and precipitation of chromium rich carbide particles in the grain boundaries where the steel encounters temperatures in the range of about 450°C to around 1000 °C, most notably in the HAZ of a weld. In addition to the loss in corrosion resistance due to chromium depletion, weld sensitization also causes a loss of fracture toughness due to the fracture path provided by the complex carbides within and along HAZ grain boundaries. [5]

Typically, the Cr carbide is a Cr-enriched $M_{23}C_6$, in which M represents Cr and some small amount of Fe. Within the sensitization temperature range carbon atoms rapidly diffuse to grain boundaries, where they combine with Cr to form Cr carbide. Because of Cr carbide precipitation at the grain boundary, the areas adjacent to the grain boundary are depleted of Cr, as shown schematically in fig. 1[6]

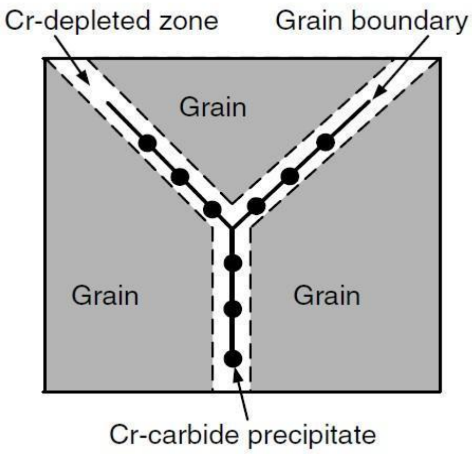


Figure 1: Grain boundary microstructure in sensitized austenitic stainless steel. [7]

Fusion welding:

Welding is one of the method of joining processes in the industry and the properties of the weldments is different to the base metal. This may sometimes cause to the failure of the component.

In Fusion welding, heat is generated by an electric arc struck between a metal to be welded and electrode. Fusion welding are i) Gas Tungsten Arc Welding (GTAW), ii) SMAW (Shielded Metal Arc Welding), iii) (GMAW) Gas Metal Arc Welding.This welding is used in all cases, the weldzone is protected by a gas, slag or vacuum, from the atmosphere which is absolutely necessary to achieve high mechanical properties and optimum corrosion resistance of the joint.

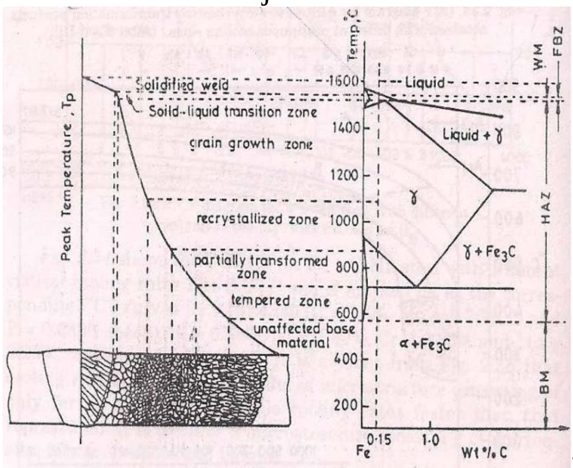


Figure 2: Different welding zone[7]

Literature Review

Rahul Unnikrishnana et al. [8] observed that steels (austenitic stainless steel) are goes to sensitization when heated to higher temperatures (400 °c to 900 °c) during the heat treatetment process or certain applications(Pressure vessels) and concluded that:Shielded metal arc welding process does not result in precipitation of carbides at the highest heat input.

Eui Gyun Na et al. [9] observed that weldments treated at 730°c with 4h holding time and than coolded in the furness are the most sensitized and concluded that:weldments that are heat treated are more sensitize than untreated weldments and parents.

Parag M. Ahmedabadi et al.[10] studied the effects sensitization on 304 stainless steel at 525°C,by using electrochemical potentiokinetic reactivation (EPR) technique and concluded that:low level of residual strain and a high fraction of annealing twins improved the resistance to sensitization.

Mohd Warikh Abd Rashid et al.[11] studied the affect of heat input on sensitization,corrosion resistance and microstructure of stainless steel by the method of XRD analysis confirmed the presence of cr_{23} c_6 in stainless steel.

Pilar De Tiedra et al.[12] evaluated the degree of sensitization in resistance spot welding by the help of electrochemical potentiokinetic reactivation (EPR) test and concluded that:sensitization has combined effect on intergranular corrosion and transgranular corrosion in the heat affected zone .IDC decreases with increasing heat input because as heat input increase s , cooling rate decreases.

Effect of heat input on the microstructure and mechanical properties of Gas Tungsten Arc Welded AISI 304 stainless steel joints is studied by **Subodh K. and A.Shahi**. They took three heat input combinations; low heat (2.563kj/mm), medium heat (2.784kj/mm) and high heat (3.017kj/mm). Dendrite size is smaller in low heat input than the medium and high heat inputs, so maximum tensile strength and ductility is possessed by the weld joint made using low heat input. They investigate that as heat input increases, the fusion zone and HAZ area also increase. So, extent of grain coarsening increase with increasing in heat input. The size of grains in HAZ of joints is found to be relatively coarser at high input and finer at low heat input. The authors recommend for prefer low heat input when welding AISI 304 SS using GTAW process because of the reason that at low heat input it gives better tensile strength and ductility.

P. Atanda et al. [14] investigated that 316L stainless steel was observed to be sensitized when heated to 750- 8500 °C and held for short soaking times in 0.5 – 2hrs. At 900 °C sensitization did not occur at 30 mins soaking time, but observed at soaking times of 1 and 2hrs. At a longer soaking time of 8 hrs,there was full desensitization. The hardness of normalized 316L stainless steel was also observed to decrease with soaking time and normalization temperature.

K.H. Lo et al. **[**15**]** investigated the effects of sensitization-induced martensitic transformation on the tensile behavior of austenitic stainless steel and concluded that:Yield strength is reduced by sensitization, but ultimate tensile strength is nearly unaffected. Strain-hardening behavior is changed by sensitization too.

Maria de Jesus Perez et al. [16] evaluated the degree of sensitization (DOS) of 304 stainless steel welded by friction stir welding (FSW) and obtain the following conclusions: Sensitization was increased by heat treatment of the stainless steel at temperatures between 400°C and 850°C.The microstructure was characterized by using optical microscope. The samples heat treated at 550°C showed the most sensitization and severe intergranular corrosion.

V. Moura et al. [17] investigated the welded component of AISI 304L steel after 20 years of service in an oil exploitation platform working at temperatures between 773k and 873k and obtain the following conclusions: Base metal and weld metal are both sensitized,The microstructure contains intergranular Cr carbides. Carbide precipitation at relatively low temperatures.

Lima et al. **[**18**]** studied the influence of temperature and time in the sensitization of stainless steel AISI 304L, AISI 321, AISI 316L, and AISI 347 pipes used in refining plants. The result showed that all steels did not present sensitization at temperature 380 ^{0}C but the temp. of 500^{0}C was critical to appearing of sensitization for both low carbon stainless steels and AISI 347 Stainless Steel, while for AISI 321 the critical temperature was 500^{0}C.

Wasnik et al. [19] worked on controlling grain boundary energy and make austenitic stainless steel resistant to intergranular stress corrosion cracking, two commercial grades of ASS 316L and 304 were used in this study and found that a very high concentration of random boundaries offers an effective means of improving resistance to both IGSCC and IGC in austenitic stainless steels. This is mainly due to material is highly resistant to sensitization.

Martin et al. [20] investigated that the degree of sensitization of austenitic stainless steel AISI 316L and intergranular corrosion (IGC) by the help of electrolytic etching in oxalic acid and electrochemical reactivation potentiokinetic tests and concluded that: The steel annealed at temperature of 650°C have chromium-rich $M_{23}C_6$ carbides along grain boundaries .

Kab et al.[21] studied the effect of sensitization on the corrosion characteristics of AISI 316L. After solution treatment at 1200°C for 4 h followed by sensitization treatment at 650°C for a predetermined time, the corrosion behavior of the sensitized sample is analyzed electrochemically by a potentiodynamic method.

Zumelzu et al. [22] investigated the influence of microstructure on the mechanical behavior of welded 316 L SS joints, the main motive was to study the behavior of welded joints considering the effect of the amount of ferrite, phase change and chemical heterogeneity and obtain the following conclusions: The best mechanical results for weldments composed of 316 L SS base metal were obtained with E316 L-16 weld metal, under conditions of low thermal contributions of 15 KJ/cm and 5% of ferrite in welded joint.

Tsai et al. **[**23**]** investigated the size and shape of the sensitization zone in 304 stainless steel welds through a designed statistically experiment. The results indicate that the width of the sensitization zone is proportion to the magnitude of the heat input.

Ahmet et al. [24] studied the effect of hydrogen in argon as a shielding gas on tungsten inert gas welding of 316L austenitic stainless steel. The penetration microstructure, and mechanical properties were examined and concluded that: The highest tensile strength was obtained from the sample which was welded under shielding gas of 1.5%H2–Ar. Grain size in the weld metal increased with increasing hydrogen content.

Jeong et al. [25] reported that when commercial 316L stainless specimens are heat treated in single phase state at 1100^0 C, abnormal gain growth (AGG) occurs and some grains are observed to be faceted with hill and valley structures in transmission electron microscopy. When heat treated at 1300^0 C normal grain growth occurs with all grain boundaries smoothly curved. At 1200^0 C AGG occurs but there is no excessively large grain as in specimen.

Karzov and Timofeev et al**.** [26] had analyzed the events of failure of pipelines made of austenitic stainless steel because from the experience of operation of power generating equipments at nuclear power plant in Russia and the other countries shows that some elements of this equipment (for most part, welded joints made of austenitic stainless steels) fails during designed service life. On the basis of the analysis it was concluded that the condition required for the initiation of inter crystalline corrosion cracking (ICCC) in austenitic stainless steels can be formulated as combined action of following three factors: the structural state of steel, chemical composition of the aqueous media and high level of stress. By changing even one of these factors, the process can be decelerated or even completely eliminated.

Kim et al. [27] studied the effect of sigma phases formation depending upon Cr/Ni ratio in AISI 316L weldments. The crack properties and toughness characteristics in AISI 316L weld metals were investigated in different chemical composition ranges of Cr and Ni contents and obtain the following conclusions: . The amount of σ in the δ-ferrite region increased significantly with increasing heat treatment time and temperature. The impact test results revealed a significant decrease in absorbed energy with increasing σ phase content.

Korinko and Malene et al. [28] had worked on the weldibility of type 304L and 316L stainless steel. Austenitic stainless steel has susceptibility to form two distinct weld defects, solidification cracking and lack of penetration, is related to chemical composition of the base and filler metal. Researchers had recommended that to help insure that types 304L and 316L SS are relatively crack insensitive and yet fully weldable, particularly when welded autogenously, limits should be placed on the Creq/Nieq ratios and sulfur content.

Raghuvir et al. [29] focused on low temperature sensitization behaviour of base, heat affected zone and weld pool in AISI 304LN stainless steel pipes of two different thickness. The specimens for the present study were taken from solution annealed pipes and welded pipes including HAZ. The specimens were subjected to thermal aging at 400^0 C and 450^0 C for different durations ranging from 125 to 8000 hours. Both the base and the HAZ of the thicker pipe material showed susceptibility to sensitization, however, they were found safe from IGC for the studied sensitization times.

Ramazan et al. [30] studied the mechanical properties of austenitic stainless steels welded by GMAW and GTAW. In this study, AISI 304L and 316L types of austenitic stainless steels were welded by GMAW using only ER 316LSi filler metal and GTAW using ER 308L and ER 316L filler metals, respectively. Mechanical properties of 304L and 316L austenitic stainless steel weldments, such as tensile properties, hardness and impact properties were determined. The results show that the yield and tensile strength, hardness and impact energy values of 304L and 316L stainless steels welded by GTAW are higher than that of welded by GMAW.

Shankar et al. [31] According to researches Solidification cracking is a significant problem during the welding of austenitic stainless steels, particularly in fully austenitic and stabilized compositions. Hot cracking in stainless steel welds is caused by low melting eutectics containing impurities such as S, P and alloy elements such as Ti, Nb. The WRC 92 diagram can be used as a general guide to maintain a desirable solidification mode during welding. Nitrogen has complex effects on weld metal microstructure and cracking. In austenitic stainless steels, segregation plays an overwhelming role in determining cracking susceptibility.

C.J. Van Niekerk and M.du Toit [32] examined the sensitization behavior of AISI 409 stainless steel during low heat input welding. They found that due to the fast cooling rate of thick section it experience sensitization at larger heat input as compared to thin sections. They also concluded that the presence of N is harmful for Ti stabilization because N consumes Ti on cooling forming TiN thus lowering the amount of Ti available for formation of TiC.Stabilization without solution treatment results in poor intergranular corrosion resistance in welded components. Solution treatments are carried out at 1100^0C for some specific time period followed by water quenching.

A.Yae Kina et. al. [33] examined the influence of heat treatments on intergranular corrosion resistance of AISI 347 weld metal. The results reveal that solution treatment leads to a better Nb redistribution improving the response to stabilization treatment. The material shows the decrease in degree of sensitization.

A study of grain growth behavior as a function of the solution temperature was conducted for a better understanding of the phenomenon occurring in the material during the solution heat treatment. At temperature below 1080^0C the microstructure of AISI 321 stainless steel appeared relatively homogenous with the average grain diameter. At temperatures equal to or higher than 1080^0C the grain growth increases rapidly. **Regina Celia De Sousa** et. al. [34] concluded that solution temperatures of 800 and 900^0C were efficient to prevent sensitization of AISI 321stainless steel.

R.V.Taiwade et.al. [35] investigated the welding behavior of AISI 304 and Cr-Mn austenitic stainless steel for single and multipass welding. Single, double and triple passes were carried out at uniform speed. Two minutes of rest time was given between the successive passes. No traces of carbides can be seen after single pass welding in both the steels. However a partial attack of carbide precipitation was observed when subjected to double pass welding. After third pass welding fully ditch sructre was observed in Cr-Mn steels wheras partially attack in 304 stainless steel. It can be seen that carbide precipitation is increasing from single to triple pass welding for both the steels.

F.F.Curiel et. al. [36] finds a new technique to improve the intergranular corrosion characteristics of 304 stainless steel. Magnetic fields of different intensity was applied to check the effect on localized corrosion at the heat affected zone of AISI 304 stainless steel grade. They conclude that the application of axial magnetic fields of low intensity during GMA welding of 304 stainless steel increased resistance to pitting and intergranular corrosion. External magnetic field applied during welding promoted Cr redistribution in the austenitic matrix, reducing the Cr depletion and so providing a more continuous and corrosion resistant passive film in the HAZ.

Shu Xin li et. al. [37] evaluated the affect of grain size on chromium carbide precipitation and intergranular corrosion of 316L stainless steel. They concluded that the 316L stainless steel has less susceptibility to intergranular corrosion as the grain size increased. This study finds that increasing grain size up to an optimum level could be an effective way to improve the intergranular corrosion characteristics.

M.Laleh and Farzad Kargar [38] studied the effect of SMAT on chromium depletion and sensitization in austenitic stainless steel. A nanostructured surface layer with a grain size about 10 nm was fabricated on AISI 304 austenitic stainless steel using SMAT. The SMATed samples shows such a low DOS value which can be considered as non-sensitized material. This can be mainly due to the existence of twin boundaries in the microstructure which are not susceptible to carbide precipitation because of their regular and coherent atomic structure and extremely low grain boundary energy.

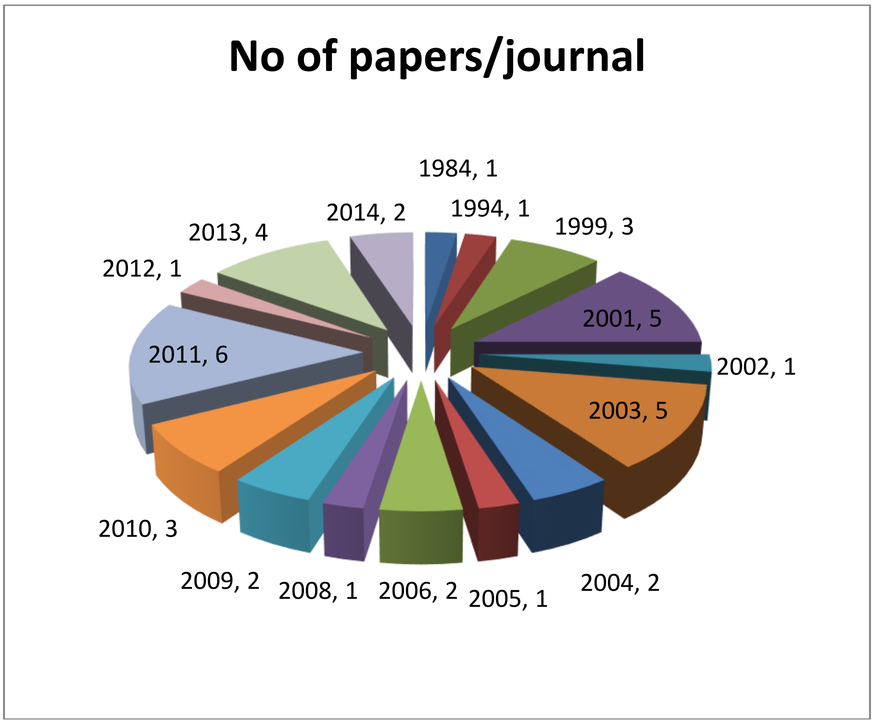
To improve penetration characteristics of 304 stainless steel, small amounts of O_2, and H_2 gas are added into the argon torch shielding gas. Weld depth is lowest when pure argon is used. In order to improve the weld depth penetration **R.I.Hsieh** et. al. [39] added 1%O_2 and 5%H_2 in the Argon gas. By adding O_2 the soluble oxygen content in the weld pool is increased which improves weld penetration. Because of its high thermal conductivity the addition of hydrogen also improve penetration and gives a larger heat input. Hydrogen effects on weld width as compared to depth, however it increases the penetration but results in wider weld.

Ahmet Durgutlu [40] also investigates the effect of Hydrogen in Argon as a shielding gas during TIG welding of austenitic stainless steel. He concludes that penetration depth and weld bead width increases with the increase in hydrogen content. The grain size in weld metal also increase with increasing hydrogen content.

Conclusion

- GTAW joints of austenitic stainless steel have superior tensile, hardness and impact properties compared with shielded metal arc and gas metal arc welded joints.
- High welding speed can cause sensitization during welding at low heat input.
- Welding conditions that promotes the formation of martensite in the HAZ can be ideal for the prevention of sensitization.
- Variation in heat input resulted in significant changes in the mechanical properties of ASS.

Analysis of Literature Review



Pie Chart: Number of papers published in year

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