The Effect of Arc Welding Process Parameters on Corrosion Resistance, Microstructure and Mechanical Properties of Austenitic Stainless Steel Welds: A Review

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Abstract: Welding is a broadly used joining process for metals and alloys. The purpose of this review is therefore to summarize the published literature and to evaluate the effect of various arc welding process parameters like welding current, welding voltage, welding speed and heat input on corrosion resistance, microstructure, strength, hardness and toughness of steel welds. After review of literature papers it was concluded that corrosion resistance varies with change in heat input and best corrosion resistance obtained using moderate heat input. The welding fusion zone has coarse structure while heat affected zone has fine grain structure.

Keywords: Arc welding, stainless steel, heat input, microstructure, tensile strength, hardness

Introduction:

Due to good mechanical properties and high corrosion resistance, steels are widely used in fabrication industry [Unnikrishnan R. et al, 2014]. Austenitic stainless steel contains nickel and chromium and nickel improves corrosion resistance. Steels are mainly joined by welding process and mostly by arc welding due to its ease to operate and availability. Welding is a most widely used permanent joining process mainly in pipelines, nuclear power plants, boilers, aircrafts, rail road equipments, constructions. A quality weld joint is that which has the properties nearly equivalent to the base metal [Unnikrishnan R. et al, 2014, Oggbunaofor et al, 2016].

Gas Metal arc welding (GMAW) offers the advantage of good welding quality and high efficiency. This is a preferred joining process for joining large metal structures. In the GMAW process, the molten metal is deposited on the base metal and forms a weld bead. In GMAW, the metal is heated with the help of arc produced between electrode and work piece. Shielding is provided with the help of inert gas. The choice of current and voltage depend on thickness of the electrode and the size of the piece to be welded. [Kambe A. G. et al, 2013].

Shielded Metal Arc Welding (SMAW) is a popular metal joining technique because of low cost, flexib-ility, versatility and portability. Shielded Metal Arc Welding use flux coated consumable electrode. Burning of electrode provide shield gas to avoid oxidation of weld and slag to carry impurities. In this welding technique, welding parameters highly affect the properties of weldment, welding cost and productivity [Dadi A. et al, 2018].

In Submerged arc welding (SAW) process metal deposition rate is high [Srivastava B. K. et al, 2010]. Submerged arc welding process has an advantage of simple setup, deep penetration, high joint efficiency, low fabrication cost and high productivity. Process parameters have great influence on quality of the weld [Srivastava B. K. et al, 2010]. Submerged arc welding is preferred where heat input is high and rate of cooling is slower [Moshi A. A. M. et al, 2016].

In welding process, heat input is responsible for thermo chemical behavior of the weld pools and microstructure of the weld. Heat input is the energy transferred per unit length of weld [Mohd Nazir N. S. et al, 2017]. Heat input affects the properties of heat affected zone and micro-constituents of the base metal [Choubey A. et al 2014]. Increase in welding speed resulted decrease in heat input [Tiwari S. P. et al, 2010]. High heat input is required in joining of large steel structures. But, in case of high heat input wider Heat Affected Zone (HAZ) obtained. So, it is necessary to pay more attention on effect of heat input on mechanical properties of Heat Affected Zone [Dong D. et al, 2014]. With increase in heat input Heat Affected Zone, depth of penetration, penetration and deposition areas increased [Shen S. et al, 2012].

Welding current is an important variable which affects heat input, melting rate, metal deposition rate and depth of penetration. At constant welding speed, if the current is high, it will result in deep penetration, excessive melting of electrode and more heat input. Arc voltage is also the main factor which affects the mechanical behavior of the weld. Welding will be smooth and sound if the arc voltage variation and hence arc length is maintained properly [Dhobale A, L. et al, 2015, Sribuddin K. et al, 2013]. [Asibeluo I.S. et al, 2015] studied the effect of current and temperature on mechanical properties of steel welds using Shielded Metal Arc Welding (SMAW) process. Investigation was done on a varying range of current . Increase in current resulted increase in temperature input which affect the microstructure and mechanical properties of the steel weldments [Asibeluo I.S. et.al, 2015, Widodo E.et al, 2018].

Welding speed or speed of the welding torch with respect to the work piece affects the depth of penetration and width of the weld pool [Singh J. et al, 2014, Ueyama T. et al, 2005]. At constant voltage and current, with increase in welding speed, the depth of penetration increased up to a maximum value but after this optimum value of penetration depth decreased with increased welding speed [Mohanta G. K. et al, 2018,Kulkarni S. S. et al, 2015]. For low speed welding weld zone will be wider [Raza A. et al, 2016]. [Prasad K. et al, 2005] investigated the effect of welding current and welding speed on the microstructure and mechanical behavior of steel plates of 16 mm thickness joined using the technique of submerged arc welding (SAW) with variable welding speed and welding current. They found variation in microstructure, hardness and toughness with varying welding current and welding speed [Prasad K. et al, 2005]. [Chuaiphan W. et al, 2008] studied the effect of welding speed on the microstructure, corrosion resistance and mechanical behavior of stainless steel sheets joined by the Gas Tungsten Arc Welding technique at three different welding speeds and found variation in corrosion potential, microstructure, tensile strength, ductility and hardness at different welding speeds. Pitting corrosion potential of the weld increase with increase in welding speed. Maximum tensile strength, ductility and hardness were observed at high welding speed [Chuaiphan W. et al, 2008].

Resistance to corrosion: Huei-Sen Wang [2014] investigated the corrosion behavior of the stainless steel (contains 25% Cr and approximately equal proportion of Ferrite and Austenite) welded at three selected heat inputs. The best corrosion resistance was obtained using an intermediate heat input of 1.4kJ/mm [Huei- Sun Wang, 2014]. [Paulraj P. et al, 2016] performed arc welding operation on Duplex Stainless Steel and Super Duplex Stainless steel and found better corrosion properties at low heat input, low temperature. [Arulmurugan B. et al, 2018] investigated the corrosion behavior of nickel based super alloy 686 weld joints. Welding process was carried out by using Gas tungsten arc welding and Pulsed current gas tungsten arc welding processes and using different filler materials. Results show that PCGTAW weldments have high corrosion resistance as compared to GTAW weldments [Arulmurugan B. et al, 2018]. [Razak N. A. A. et al, 2014] investigated the effect of welding voltage on corrosion resistance of MIG welding low carbon steel welds. They found that the corrosion resistance increased with increase in welding voltage.

Microstructure: Macro and micro structural analysis have confirmed that the welding process parameters affect the microstructure of the weld in the form of grain size and phase structure [Cico P. et al, 2011]. Low heat input is commonly applicable in industrial application due to refined grains microstructure. But, low heat input has less penetration and can produce weak weld joint. High heat input is preferably used in shipping industry due to deep penetration. However, high heat input may cause coarse grains and results in less toughness [Mohd Nazir N. S. et al, 2017, Tewari S. P. et al, 2010]. Weld joints fabricated by GTAW technique have coarse microstructure while PCGTAW welds have finer microstructure [Arulmurugan B. et al, 2018].[Mohammed G. R. et al, 2017] studied the effect of heat input on microstructure change of steel welds using low heat inputs. Results showed single-phase structure in DSS welds while Austenitic or austenitic-ferritic structure in ASS welds and Austenite to ferrite ratio depends on heat input during the welding process [Mohammed G. R. et al, 2017]. Kurt H. I. et al [2018] have investigated the structure of Austenitic stainless steel plates joined together using Arc Stud Welding technique. Results showed the formation of δ- ferrite structure in welded region because of higher heat input during welding [Kurt H. I. et al, 2018]. Less solidification time (rapid cooling) promotes finer grains while slow cooling rate results in coarse grains [Dong D. et al 2014, Kumar R. et al, 2014]. The effect of the process parameters of the SMAW process on the microstructure properties of low carbon steel weldments was studied and they found that the microstructure of the fusion area was completely different from that of the area affected by heat (HAZ). HAZ contains large ferrite grains and perlite colonies [Boumerzoug Z. et al, 2010]. Fusion Zone has coarse structure while Heat Affected Zone has finer structure obtained [Khamari B. K. et al, 2018, Baskutis S. et al, 2013]. In fusion zone transformation of ferrite to austenite is highly affected by heat input and cooling rate [Mourad H. I. et al, 2012, Mukesh et al, 2013]. As compared to single pass Gas Tungsten Arc Welding, improved microstructure obtained in multipass welding [Nair B. S. et al, 2007].

Mechanical Properties: Bodude M. A. et. al. [2015] performed oxy-acetylene welding and SMAW process at various welding parameters on 10 mm thick low carbon steel specimen. They discovered that the hardness is reduced with the increase of the heat added, but the impact force of the weld increased with the increase of the heat added [Bodude M. A. et al, 2015]. With increased heat added tensile strength first increased to some extent and then started decreasing [Razvi S. A. et al, 2018]. Use of Cr-Mn-N steel electrode in Shielded metal arc welding results in favourable microstructure but inferior mechanical properties compared to base metal due to coarse and dendritic structure [Mohammed R. et al, 2018]. TIG welding results in better mechanical properties as compared to SMAW. The ultimate tensile strength of the TIG weldment is higher as compared to SMAW weldment [Raju L. S. et. al. 2015, Balsaraf D. D. et al, 2013]. In case of submerged arc welding, different welding parameters like current, voltage, temperature, wire feed rate, welding speed and electrode stick-out have direct effect on hardness and strength of the weld [Kanjilal P. et al 2006]. Keeping other parameters constant and increased electrode stick-out, hardness of the weld increase but strength decrease [Srivastava B. K. et al, 2010]. Hardness and tensile strength depends on electrode material, filler material, welding speed and heat input [Naik A. B. et al 2018]. Due to the formation of martensite and banite structures, the hardness of the welding area is greater than that of the base metal [Raza A. et al 20]. In case of austenitic stainless steel weldments fabricated using shielded metal arc welding technique, tensile strength decreased with increase in heat input, while hardness of weld increased with increase in heat addition [Choubey A. et al, 2014, Dong D. et al, 2014]. Paulraj P. et al. [2015] have studied the effect of Gas Tungsten Arc Welding (GTAW) process parameters on mechanical properties of Duplex Stainless Steels (DSS) and Super Duplex Stainless Steels (SDSS). SDSS have higher strength because it contains chromium and molybdenum. They found the tensile strength of all weldments 5-10% higher than the base meterial. Strength of the weld decreased with increase in heat added because of decrease in ferrite content and due to more coarse grains. Tensile strength and impact toughness have improved slightly at higher nitrogen content in shielding gas due to strengthening of austenitic phase [Paulraj P. et al, 2015]. In general Arc Welding steel weldment Hardness value is more in Heat Affected Zone as compared to Fusion Zone due to finer grain structure of HAZ [Khamari B. K. et al, 2018]. Plasma Arc Welding (PAW) joints show better tensile and impact properties as compared to Constant Current Gas Tungsten Arc Welding (CCGTAW) joints [Lakshminarayan A. K. 2019]. Hardness decrease with increase in welding current and decrease in welding speed [Prasad K. et al, 2008]. Use of flux in GMAW increase tensile strength and hardness of the GMAW joints [Huang H. Y. et al, 2010]. Due to the presence of a higher percentage by weight of carbon, the hardness of TIG welded joints was greater than GTAW joints [Pandey C. et al, 2017]. The toughness of fusion zone increased due to formation of the austenite, while that of the heat affected zone (HAZ) decreased due to coarse martensite grains and the formation of carbides [Hao K. et al, 2017]. In Submerged arc welding process improved tensile strength and hardness obtained by increased number of passes [Moshi A. A. M. et al, 2016]. Increased welding voltage and current result in increased heat input and hence increased hardness and decreased tensile strength, yield strength and impact toughness [Talabi S. I. et al, 2014]. With increased welding speed, the tensile strength increased [Chauhan M. J. et al,2017]. In case of TIC welding impact strength of the weld was found to be better than base metal but ultimate tensile strength was lower than base metal [Khan M. R. et al, 2017]. [Albdiri M., 2018] studied the welding current and its effect on mechanical properties of Austenitic Stainless Steel pipes and found highest tensile strength at 900°C temperature and highest bending strength and ductility at 700°C.

Conclusions:

From the above study following conclusions were made:

- Corrosion resistance of the weld varies with change in heat input and voltage and best corrosion resistance obtained using moderate heat input and higher voltage.
- The welding fusion zone has coarse structure as compared to base metal.
- TIG welding welds have higher ultimate tensile strength as compared to SMAW welds.
- Increased welding voltage and current results in higher heat input and hence higher hardness of the welded region.

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