ISSN 2395-1621

A review on effect of welding parameters on mechanical properties and microstructure of butt welded mild steel plates

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ABSTRACT

The objective of this paper is to study the effects of different welding parameters on the mechanical properties and microstructure of butt welded mild steel plates. Different researchers have investigated the effect of different welding parameters such as heat input, welding speed, number of passes, welding sequence, gas flow rate, shielding gases on the mechanical properties, residual stresses, strength, distortion and microstructure of Heat Affected Zone (HAZ). The welding methods used by them were also different such as SMAW, GMAW, TIG, MIG, FSW. It has been found that the welding parameters mentioned above affects greatly on the mechanical properties. The microstructure in HAZ undergoes noticeable changes due to heating and cooling cycles during the welding. As the behavior of material depends greatly on its mechanical properties and microstructure, it is essential to study the effect of welding parameters on the mechanical properties and microstructure of the material. The selection of proper welding parameters is necessary so as to achieve maximum strength in welded joints. This paper deals with the presenting different researches related with the study of different welding parameters on the mechanical properties and microstructure of different materials which were welded using different welding processes.

Keywords: Welding parameters, mechanical properties, microstructure, heat affected zone.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Generally welding can be defined as a process in which two or more pieces of metal are joined together by the application of heat, pressure or combination of both [2]. Most of the processes may be grouped into two categories: Pressure welding in which the weld is achieved by pressure; and Heat welding in which weld is achieved by heat. Heat welding is the most common welding used today. Welding is used extensively in all sectors of manufacturing including guide way for trains, ships, bridges, building structures, automobiles and nuclear reactors to name a few[5]. It requires a continuous supply of either direct or alternating electric current which creates an electric arc to generate enough heat to melt the metal and form a weld. However, during the heating and cooling cycles of a welding process, the base material as well as weld material undergoes changes in mechanical properties and microstructure. The extent of change in these properties that has been occurred due to welding depends on the selection of different welding parameters. The proper selection of welding parameters is required for obtaining good results related with the physical, chemical and mechanical behavior of the material.

Thin plates are widely used in aerospace, naval, and automobile industries to reduce the weight of component. Large structures are formed by connecting different parts to each other by welding. To avoid the failure of the structure, the weld region or weld metal should have equal or more strength as compared to the base metal. For this selection of welding parameters plays very important role as all properties are related directly or indirectly with the welding parameters. Hence it is essential to study the effect of different welding parameters on the mechanical properties and microstructure of the material after welding.

Here, the detailed study carried out by different researchers related with the effect of different welding parameters on the mechanical properties and microstructure is presented in brief.

Subodh Kumar et al.[1] have studied the influence of heat input on the microstructure and mechanical properties of gas tungsten arc welded 304 stainless steel (SS) plates of sizes 200mm x 100mm x 6mm with filler of 308 SS solid electrode of 3.15 mm diameter in two number of passes. The shielding gas flow rate of industrially pure Argon= 15 L/min was kept constant. As the welding current is the most influential variable since it affects the current density, three different heat input combinations corresponding to different welding currents i.e. 120 A (low heat input 2.563 kJ/ mm), 150 A (medium heat input 2.784 kJ/mm) and 180 A (high heat input 3.017 kJ/mm) combinations were selected. For studying the effect of heat input on tensile strength, the specimens were tested on a servo hydraulically controlled digital tensile testing machine of 400 kN capacity. After testing it is found that the joints made using low heat input exhibited higher ultimate tensile strength (UTS) than those welded with medium and high heat input. Also it is found that all the tensile specimens fractured in the base metal which indicates that weld metal in all the joints possessed higher tensile strength than the base metal and thus joint efficiencies are more than 100 %. It is observed from the optical micrographs that as heat input increases the dendrite size and inter-dendritic spacing in the weld metal also increase. This is due to the fact that at low heat input, cooling rate is relatively higher which permits lesser time for the dendrites to grow, whereas at high heat input, cooling rate is slow which provides ample time for the dendrites to grow farther into the fusion zone.

Hence from this study we can conclude that that low heat input should be preferred for welding AISI 304SS using GTAW process because it gives good tensile strength and ductility. Also the size of the HAZ and the extent of grain coarsening obtained in these weld joints is less.

Wichan Chuaiphana et al. [2] carried out experiments to find out the effect of welding speed on the microstructures, mechanical properties and corrosion behavior of AISI 201 stainless steel sheets. An automatic gas tungsten arc welding method (GTAW) was used for welding AISI 201 stainless steel sheets plates of dimensions of 150 x 100 x 2mm. To find out the effect of welding speed on the microstructures, mechanical properties and corrosion behavior of AISI 201 stainless steel sheets three welding speeds designated as 1.5 (mm/s), medium (2.5 mm/s) and high (3.5 mm/s) were operated and joints made were subjected to analysis of the microstructures, mechanical and corrosion properties of the joints. It was found that excess penetration was occurred for the welding speeds lower than 1.5 mm/s whereas for the welding speeds more than 3.5 mm/s incomplete penetration were observed hence the range of speed is selected varying from 1.5 mm/s to 3.5 mm/s.

After welding, specimens were subjected to analysis of the microstructures, mechanical and corrosion properties of the joints. From microstructure study it was concluded that with increase in the welding speed the width of face and root of weld metal decreases. Also with increase in welding speed , the dendritic size and inter dendritic spacing in the weld metal reduces because, at high welding speed, heat input is lower and cooling rate is relatively higher due to which less time is available for grain growth. From microhardness study it was observed that as the indentor traverses outwards from the center of the weld/fusion zone toward the fusion boundary, microhardness increases. The reason is again related with the heat input and cooling rate. As the welding speed increases, the pitting corrosion potential of weld metal also increases, due to small dendrite sizes and less inter-dendritic spacing in the fusion zone. It was found from the tensile testing that the ultimate tensile strength (UST) increases and percentage elongation decreases with increasing welding speed.

Based upon the present study it is recommended that welding speed 3.5 mm/s (high speed) should be preferred when welding AISI 201 stainless steel using GTAW process because of the reason that besides giving good mechanical properties (tensile strength and hardness), high corrosion resistance, the size of the weld bead and the extent of grain coarsening obtained in these weld joints are less.

V. Subravel et al [3]. studied the effect of welding speed on tensile and microstructural characteristics of pulsed current gas tungsten arc welded AZ31B magnesium alloy joints. For finding the effect they have considered five joints fabricated using different levels of welding speeds (105,115,125,135 and145 mm/min) The material used was rolled AZ31B magnesium alloy plates with a thickness of 3 mm cut into the required size (150 mm × 150 mm). Plates were welded using single pass welding procedure and Argon gas was used as a shielding gas with a constant flow rate of 20 L/min. They have carried out the microstructural analysis using a light optical microscope incorporated with an image analyzing software. From the micrographs we came to know that the welding speed influences the average grain diameter of fusion zone in AZ31B magnesium alloy. The joint fabricated with a welding speed of 135 mm/min contained finer grains as compared to other. Whereas the joint fabricated with the welding speed of 105 mm/min shows the coarser grains. While correlating the tensile properties with the average grain diameter we can say that the finer grains have higher tensile strength. The tensile test was carried out in a 100 kN, electro mechanically controlled universal testing machine. From the results of tensile testing it is observed that the joint fabricated with a welding speed of 135 mm/min exhibited high yield strength (165 MPa), tensile strength (214 MPa) and elongation (7.2%). From the macrostructures of the joints it is seen that at higher speed (145mm/min) partial penetration is observed due to low heat input whereas at lower speed (105mm/min) a burn through of the weld and the surface breaking defects were observed due to higher heat input. This affects on the tensile properties of the joints. Due to optimum heat input, the joint made with speed of 135mm/min shows full penetration and hence it has maximum tensile strength. Also the hardness of the joints fabricated with a welding speed of 135 mm/min showed higher hardness (HV 66) in the fusion zone.

Zakaria Boumerzoug1 et al. [4] in their work, studied the effect of arc welding on microstructures and mechanical properties of industrial low carbon steel (0.19 wt. % C). For welding the steel plates, steel electrodes were used to deposit the welds and the welding process used was shielded metal arc welding process. Some parts of welded sheets of a gas cylinder were used as the sample specimens. For studying the microstructure of the specimen before and after welding i.e. for metallographic observations, the specimens were etched with 2% nital for 20 seconds and then the microstructure of base metal, weld and heat affected zone were specified. Standard size specimens were prepared for Electron Back Scattered Diffraction analysis. For checking the hardness across the weld metal microhardness tester with 2 kg load have been used. From the micrographs it was found that the average grain size was 10 μm. Also it is observed that elongation of ferrite grains was affected by the direction of heat flow.

In the heat affected zone of steel welds Widmanstatten ferrite and some colonies of pearlite were observed. After welding, when cooling cycle was going on; two phase transformation was observed in the heat affected zone. The first was the high temperature transformation of δ-Fe to γ-Fe. And the second transformation was observed at relatively low temperature from γ-Fe to α-Fe. Due to high temperature gradients and chemical gradients evolved during the process, heterogeneous microstructure was observed. The hardness values of 178-250 HV were observed at location within 1 mm from the base metal, through the HAZ across the weld metal to the other base plate. The maximum values of hardness were situated in the area of weld metal and HAZ and hence we can say that the location of maximum hardness is specific.

Mr. Parth D Patel et al.[5] analyzed and compared the experimental data and predicted data in MAG-CO2 welding technique. Plates of 5mm thickness having double grooves of C20 low carbon steel were used as test samples for DOE of MAG-CO2 welding. The input parameters considered for MAG-CO2 welding were welding current, wire diameter and wire feed rate whereas for TIG welding the parameters were welding current and wire diameter. The output parameter was weld strength for both MAG-CO2 welding and TIG welding techniques. 27 different readings were taken for Design of Experiments [DOE] in which the values considered of current were (100, 140 and 180A), wire diameter (0.8, 1 and 1.2mm) and wire feed rate of (2,3 and 4m/min). For MAG-CO2 welding constant voltage power source was used.

After completion of experiment the hardness for each work piece was predicted by using NeuroXL Predictor software and changes in experimental hardness and predicted hardness was compared. The results of both the cases were found to be in good agreement with each other and the percentage error was less than 5% which is in allowable margin.

A K Lakshminarayanan et al.[6] calculated microstructure, tensile and impact toughness properties and fracture location of friction stir welded AISI 1018 mild steel. The AISI 1018 mild steel plates with thickness of 5 mm were friction stir welded by tungsten based alloy tool with tool rotational speed of 1000 r/min and welding speed of 50 mm/min.

For evaluating the tensile properties of the plates an electromechanical controlled universal testing machine of 100kN in capacity was used for tensile testing. In tensile testing, the failure was occurred in the base metal region hence we can say that the transverse tensile strength and yield strength of the FSW joint were higher than the base metal. The nature of failure was ductile. However the elongation of the stir zone was less compared to base metal indicating the lower ductility of the stir zone. The impact toughness of unwelded base metal was observed to be 32J and that of FSW joint was 28J which indicates that the impact toughness decreased by 34% after welding. The reasons for reduction in ductility and toughness could be the presence of tool debris at the bottom of the stir zone. Vickers microhardness tester with a load of 0.5 N for 15 s was applied for evaluating the hardness of the base metal.

From the microstructure studies it was observed that the base metal has the microstructure of equiaxed ferrite grains with approximately 20-30 pm in diameter and smaller grains of fine pearlite whereas the weld region contains five distinct regions including the nugget, a subregion inside the nugget on the advancing side (swirl zone) , thermo-mechanical affected zone (TMAZ) , fine grained heat affected zone (FGHAZ) , and coarse grained heat affected zone (CGHAZ) which indicates the a transition from the base metal to the nugget.

G. Padmanaban et al.[7], developed an empirical relationship to predict tensile strength of the laser beam welded AZ31B magnesium alloy by incorporating process parameters such as laser power, welding speed and focal position. To determine the feasible working limits of the laser beam welding parameters trial and error method was carried out using 6 mm thick rolled plates of AZ31B magnesium alloy. It is found that the range of laser power for full penetration was 2.5 to 3.5 kW and welding speed should be 4.5 to 5.5 m/min. Depending on this working range, Design matrix is developed by considering three levels of each factor.

Experiments were carried out on the Rolled plates of 6mm thickness of AZ31B magnesium alloy of size (300 x 150 x 6mm). LBW joints were produced using a CO_2 laser. Tensile test was carried out using a 100kN, electro-mechanical controlled universal testing machine. An empirical relationship is developed with the help of mathematical and statistical results to predict the tensile strength of the joints. The adequacy of the developed relationship is tested using the analysis of variance (ANOVA) technique. Again Response surface methodology is used for optimizing the process variables. They have found that at lower laser power (2500W), the tensile strength of LBW joints is higher and with increase in laser power the tensile strength decreases. Also from the response graph it can be concluded that at lower welding speed (4.5 m/min), the tensile strength of the LBW joints is lower. When the welding speed is increased from 4.5 m/min, the tensile strength also increased. A maximum tensile strength of 212 MPa is obtained under the welding conditions in which the laser power is 2.5kW, welding speed of 5.0

m/min and focal position of -1.5 mm. By comparing the results we can say that the developed relationship can be effectively used to predict the tensile strength of laser beam welded joints at 95% confidence level.

K. Devendranath Ramkumar et al.[8] concentrated on the optimization of process parameters i.e. current and welding speed in order to achieve the maximum penetration in the bead on plate Gas Tungsten Arc Welding (GTAW) of super-duplex stainless steel thick plates of dimensions 200 x 60 x 5 mm by autogeneous-automatic mode.

To study the influence of welding current and speed Taguchi's L9 orthogonal array was used for design the experiments in which nine experiments were carried out. As influencing parameters considered are two, a two factor three level array was used and hence the degrees of freedom would be 4. In this method, the optimum value could be determined by the S/N ratio (signal-to-noise). The larger S/N ratio, better will be the performance characteristic. For the values of current varying from 200-250 A and welding speed varying from 150-250 mm/min corresponding values of weld penetration, bead width and S/N have been noted down. A maximum penetration of 3.4439 mm with a heat input of 1.17 kJ/mm was obtained on employing a current of 250 A and a welding speed of 150 mm/min. The response of S/N ratio to the current shows that as the current increases, the depth of penetration increases. From microstructure studies it can be seen that proper fusion has been occurred. The average ferrite content in the top, middle and bottom locations of the weld zone was found to be 66.67%, 67.49% and 55.76% respectively whereas the parent metal has 48.06%. The average weld hardness was found to be 312, 322 and 309 HV at the top, middle and bottom locations respectively with peak value of 335 HV at the weld metal. Whereas from tensile testing the tensile strength 0f 850 MPa , ductility 30% and impact toughness 150J were obtained

To observe the response of weldmens to sudden loading, Charpy V-notch impact test was carried out which showed that the average impact toughness of the weldments was found to be 150 J which is lower than the base metal. From this study author confirmed that autogeneous gas tungsten arc welding can be used for super-duplex stainless steel under given process parameters for more benefits.

Study of **Hee Seon Bang** et al.[9] aims at establishing the possibility of application of laser-arc hybrid welding for austenite stainless steel (STS304L) of 13 mm thickness. For this they have used 12 kW CO_2 laser combined with the gas metal arc welding (GMAW) process. A comparison of CO2 laser-GMA hybrid butt welded joints and submerged arc butt welded(SAW) joints has been carried out by them. The WM and HAZ in SAW are found wider and the thermal behavior of SAW shows semi-ellipsoid isothermal distribution. However, the thermal behavior of the hybrid welding shows a combination of semi-ellipsoid and line distribution that characterizes the heat source of both arc and laser welding. While comparing the results of the hybrid welded joints with those of the SA welded joints, the value of the temperature distribution on the hybrid welded joints by high density heat source is found much higher than that of the SA welded joints. The temperature at the weld region is exposed to faster rate of heating and cooling in hybrid welding than SAW. The residual stress was found to be 13–15% less in the hybrid welded joints than in the SA welded joints because of faster cooling rate and smaller volume of WM than SAW but the distribution of stress was found to be similar in both the cases. While talking about the micro-structures of the weld metal in hybrid and SA welded joints exhibit very fine dendritic structure which is formed during solidification of the filler metal. While the filler metal solidifies, nucleus forms and it develops as dendritic growth in the micro-structures due to the composition differences between the structure that solidifies earlier stage and later stage. Also, there are no weld defects evident in the weld metal such as hot /solidification crack and porosity. However, as a result of larger heat input of SAW process, the HAZ of SA welded joints became more than two times thick, than that of hybrid welded joints. Finally we can conclude that for the welding process, in terms of the mechanical and microstructure characteristics, hybrid welded joints seems to be advantageous compared to SA welded joints. From the results, authors could confirm that it is more reasonable to replace hybrid CO2 laser- GMA welding with SAW for butt joint of STS304L thick steel.

Jiamin Sun et al.[10] have investigated the welding deformations in low carbon steel thin-plate joints induced by LBW and CO2 gas arc welding by means of both numerical simulation technology and experimental method. The dimension of each weld specimen is 300 mm×100 mm×2.3 mm made of low carbon steel (Q235). The results indicate that the out-of-plane deformation of thin-plate joint can be largely reduced if CO2 gas arc welding method is replaced by LBW. Also the numerical results indicate that the residual stresses induced by LBW are superior to those produced by CO2 gas arc welding both in distribution and in magnitude. But the LBW involves several complex phenomena like the formation of a keyhole, ionization and vaporization of material, circulation of molten metal within the weld pool, solidification at the liquid-solid interface, and so on. In comparison to CO2 gas arc welding LBW can significantly reduce the welding deformation. The maximum deflection resulted from the thin-plate welded by LBW was only 0.23 mm, while that resulted from CO2 gas arc welding was 8.7 mm. Also, the range with high longitudinal tensile stress in the joint welded by LBW was found to be significantly narrower than that generated by CO2 gas arc welding and the maximum value of longitudinal residual stress generated by the former is smaller than that caused by the latter. The simulation result shows the welding distortion predicted by large deformation theory is different from that simulated by small deformation theory to some extent. The deflections predicted by the large deformation theory are in good agreement with the measured data. Hence we can say that to accurately predict welding distortion in a thin-plate joint the large deformation theory should be used.

P. Sathiya et al.[11], performed CO_2 laser welding on super austenitic stainless steel sheets with optimized process parameters. High beam power (3.5 kW) and low travel speed (1200 and 2400 mm/min) with nitrogen as the shielding gas was used. The butt welding trials were carried out on a 110 x 55 x 5 mm sheet of AISI 904 L super austenitic stainless steel with 1.2 mm diameter of super austenitic stainless steel solid filler wire. They have conducted the butt welding experiments on three different combinations of shield gases 50%He + 50%Ar, 50%He +

45%Ar + 5%O_2 and 45%He + 45%Ar + 10%N_2 at a constant flow rate. The full penetration is achieved without any defects. The weld shape is shallow and wide under 50% He + 50%Ar shielding gas mixtures. When a small amount of oxygen (5%) and nitrogen (10%) is mixed into the 50%He + 45%Ar and 45%He + 45%Ar shielding gas mixtures, the weld shape changes from the shallow type to the deep narrow shape. While considering the microstructure, In GMAW upper zone, 50%He + 45%Ar + 5%O_2 shielded weld metal has more primary dendritic and in the lower zone weld metal a high amount of primary dendritic present in 45%He + 45%Ar + 10% N_2 shielding gas. The 50%He + 45%Ar + 5%O_2 hardness values are higher than the other two shielded weld metal hardness in GMAW (upper) weld zone. Due to plasma plume suppression in addition of nitrogen shielding gas, the hardness values are higher in 45%He + 45%Ar + 10% N_2 shielded laser zone. The tensile strength is less in 50% He + 50%Ar shielded weld when compared to other two shielded weld tensile strength. The fracture surface appeared in pure shear fracture in 45%He + 45%Ar + 10% N_2 and in 50%He + 45%Ar + 5%O_2 shielded fracture surface appears ductile with partially cleavage fracture occurring. 50%He + 45%Ar + 5%O_2 shielded weld joints exhibit higher impact toughness values, and the enhancement in toughness value is approximately 36% compared to base metal. The impact specimen fracture surfaces of the different shielding gas laser– GMAW hybrid welded joints show mixed mode fractures, that is, ductile and cleavage fractures.

Andrés R. Galvis et al.[12] studied the weld joints manufactured with a welding electrode type 308L and by three different arc welding processes shielded metal arc welding (SMAW), gas metal arc welding (GMAW) and flux cored arc welding (FCAW) in a AISI/SAE 304 in order to compare the failure mechanisms associated with their mechanical and micro structural properties. They have analyzed the chemical compositions by optical emission spectroscopy. To study the variations in the mechanical properties of each process and to find out their most probable failure modes by means of a fractographic study; fatigue tests have been performed. They have observed three different fracture modes at the welding joints that showed correlations with microstructural changes produced during the welding process. The reason of first type of failure observed at the weld root region was the nucleation of the crack. The origin of the second failure mode was at the heat affected zone (HAZ), where the crack nucleated due to a variation in the grain size produced by the process and then further propagated through the edge of the weld. The third mode of failure was observed due to stress concentration in the weld due to the presence of exogenous inclusions generated by the welding process.

II. CONCLUSION

From the above literature it can be concluded that welding parameters affects directly on the mechanical properties and microstructure of the welded joints. For achieving the maximum strength of welded joints proper selection of welding parameters is essential. From this point of view we are going to study the effect of welding parameters i.e. Welding current, welding voltage and gas flow rate on the tensile strength and microstructure of mild steel plates of dimensions 150 x 50 x12mm which were welded by using Metal Active Gas(MAG) welding with three number of passes.

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