Influence of process parameters of TIG welding process on mechanical properties of SS304L welded joint

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Abstract - ***The purpose of this study is to study the effects of various process parameters (welding current, filler materials and groove design) of tungsten inert gas welding (TIG) on aspect ratio, hardness and impact strength of SS304L welded joint. Aspect ratio is obtain by taking the ratio of bead penetration to bead width. This bead diamensions can measure by vernier calipers. Weld joint quality is depends on the bead diamensions. Bead diamensions of the welded specimens are mainly dependent on welding current .So that, Aspect ratio is our response parameter .Rockwell hardness test set up gives hardness at fusion zone, heat affected zone and base metal zone. Impact strength of a material is termed as the resistance offered by the material against the suddenly applied load. Impact strength is generally depends on the temperature change. This SS304L material is generally use in industrial field such as steam power generation ,automotive engineering, biomedical engineering and dairy industry, petrochemical engineering and chemical engineering .So that above mentioned mechanical properties are require to estimate. Hence in this study, the above parameters of TIG welding for hardness, impact strength and aspect ratio of SS304L welds will optimize by using Taguchi orthogonal array (OA) experimental design and other statistical tools such as Analysis of Variance (ANOVA) techniques by Minitab 16 software. Analysis of Variance is used to analyse the influence of parameters during machining. The results of present work indicate that welding parameters have significant influence on impact strength, hardness and Aspect ratio. Welding current is most affecting parameter to hardness and aspect ratio both whereas groove design is the most affecting parameter to impact strength.***

Key Words: **SS304L, TIG welding, Impact strength, Hardness, Aspect ratio, ANOVA.**

1. INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. The technique of using fluxes during TIG welding enabled steels of around 6 mm to be welded with single pass in square butt configuration without addition of filler metal [1, 9]. Steel weld joints made by conventional tungsten inert gas (TIG) welding process exhibit good impact toughness because of low micro-inclusion content in welds. Although conventional TIG process has good toughness, its productivity is limited. A variant of TIG known as A-TIG is gaining importance in the fabrication of power plant components worldwide [2]. The welding current of TIG welding effects on the morphology, microstructure, tensile property and fracture of welded joints of austenite stainless steel due to heat input. The problems like hot cracking, carbide precipitation phase and sigma phase can reduce significantly the mechanical property of this welded joint. Therefore, there is a need to find the optimization current as one of parameters for TIG welding on 316 stainless steel to reduce welding defects and to achieve better mechanical properties [3, 8]. The maraging steel is usually welded though Gas Tungsten Arc Welding (GTAW) and Plasma Arc Welding (PAW) with filler additions, in fact the maraging steels have demonstrated good weldability in a variety of welding techniques, including laser welding [4]. The chemical composition of WM and level of welding heat input will directly affect the phase structure and further impact the cryogenic toughness of the weld joint. Narrow gap welding technology, with the obvious advantage of large thickness penetration during steel plates welding processing, was reported to be applied in jointing the ITER TFC structure parts. Moreover, the small size of groove could reduce filler metal usage and save processing time [5]. The acceptance of the welded samples is most important. In order to meet its requirements and standards, destructive and nondestructive evaluation of these materials is done in various stages to evaluate weld quality. The weld joint inspected found that it does not meet its requirements due to lack of penetration, under cuts, cracks etc. even though necessary precautions were taken during welding process. Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays. This technique provides an efficient, simple and systematic approach to optimize design for quality, performance and cost [6]. Tungsten Inert Gas (TIG) welding using multiple passes is one of the main process used for joining of the thick stainless steel plates. The joint design also has different possible options like narrow groove, double V groove (X) or J type groove based on the type of weld joint requirements [7]. The welding residual stress through the thickness of stainless steel pressure vessel can be evaluated by using the FEM simulation [10]. Stainless steels are an important class of engineering materials due to their high corrosion and oxidation resistance. Austenitic stainless steels are a group of steels that contain nominally 19% chromium and 9% nickel .This group of steels exhibit a highly attractive combination of high strength, good ductility, excellent corrosion resistance and a reasonable weldability [12]. Among all the welding variables in arc welding processes welding current is the most influential variable since it affects the current density and thus the melting rate of the filler as well as the base material [14].From literature reviewed of TIG welding on different steel materials, it is observed that no systematic work on the effect of weld groove design and different filler material on the impact strength, hardness and aspect ratio of the welded joint of the SS304L material. In view of the fact that arc welding processes like GTAW offer a wide spectrum of thermal energy for joining different thicknesses of steels it was considered important that undertaking the present study would be beneficial in gaining an understanding about the metallurgical aspects that affect the service performance of these welded joints made using different heat input combinations.

1.1 Basic mechanism of TIG welding

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours [1]. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000deg.C and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig.1.

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source.

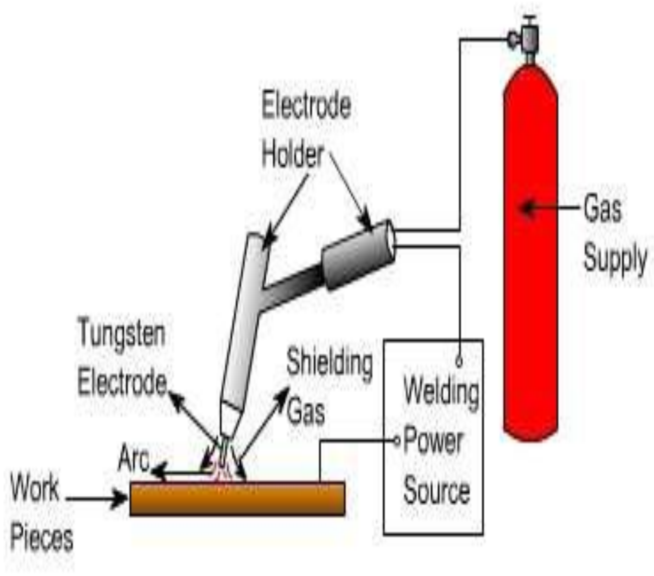

Figure 1.Schematic diagram of TIG welding set up

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimetres. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to these value is equally crucial when the electrode is short circuited to the work piece, otherwise excessively high current will flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

1.2 Process parameters of TIG welding

The parameters that affect the quality and outcome of the TIG welding process are given below.

1) Welding Current

Higher current in TIG welding can lead to splatter and work piece become damage. Again lower current setting in TIG welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of filling materials. Fixed current mode will vary the voltage in order to maintain a constant arc current.

2) Welding Voltage

Welding Voltage can be fixed or adjustable depending on the TIG welding equipment. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. Too high voltage, can lead to large variable in welding quality.

3) Inert Gases

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. **Argon** generally provides an arc which operates more smoothly and quietly. Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminium, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminium and copper. Helium argon mixtures may be used for low alloy steels, aluminium and copper.

4) Welding speed

Welding speed is an important parameter for TIG welding. If the welding speed is increased, power or heat input per unit. Length of weld is decreases, therefore less weld reinforcement results and penetration of welding decreases. Welding speed or travel speed is primarily control the bead size and penetration of weld. It is interdependent with current. Excessive high welding speed decreases wetting action, increases tendency of undercut, porosity and uneven bead shapes while slower welding speed reduces the tendency to porosity.

2. EXPERIMENTAL WORK

Experimental work is carried out on SS304L material of 6 mm thickness by manual TIG welding process.

2.1 Material selection

SS304L stainless steel is selected over other materials because of its distinct properties, cheaper cost and its availability in market.SS304L material used in pressure vessel and dairy containers. Chemical composition of SS304L is shown in table 1.This grade has high corrosion resistance and can be operated at elevated temperature. The work piece detail is as under:
Diamensions of specimen: 60mm*30mm*6 mm
No. of specimens: 9

% alloy	SS304L	ER304L	ER308L	ER309L
C	0.035	0.02	0.03	0.02
Si	0.460	0.4	0.4	0.5
Mn	0.900	1.8	1.6	1.85
Cr	18.390	19	20	24.5
P	0.029	0.045	0.03	0.045
Ni	8.150	9.8	10	12.8
Mo	0.18	0.75	-	0.15
S	0.01	0.03	0.03	0.03

Table 1. Chemical Composition of Base material and Filler material

2.2. Welding set up

Extensive welding trials were conducted in manual TIG welding set up having capacity of 400 A with 60% duty cycle as shown in fig.2.This set up available at Apex Engineering, Dediyasan ,GIDC ,Mehsana. The welding parameters are as shown in Table 2.The arc was moved along the centre line of the welds.

Figure 2.GTAW set up (Courtesy: Apex Engineering, Dediyasan, GIDC-II, Mehsana)

2.3 Conducting the experiments as per design matrix

In the present work, plates of SS304L of 6mm thickness and 60 mm lengths were butt joined using three different types of filler rod and three levels of welding current on three different types of groove design by manual TIG welding process. This three parameters were taken as variable for present study and their three levels were chosen for which responces were measured, for which L9 orthogonal array was selected as experimental design method. This parameters with their levels were shown in table 3.Before welding all sheets were cleaned chemically by acetone in order to remove any source of contaminants like rust, dust, oil etc. Single pass welding was performed on the samples under the conditions mentioned below.

Welding constant parameters:
Electrode type: 98% tungsten, 2% thoriated
Shielded gas type: pure argon
Electrode dia.: 2.4 mm
Current type: DCEN
Flow rate: 10-12 l/min
Voltage: 24 V

Parameters	Level 1	Level 2	Level 3
Welding current(A)	120	150	180
Groove design	V	U	V & U
Filler rod	ER304L	ER308L	ER309L

Table 2.Different parameters with their levels

Figure 3.Welded specimen sample

Experiment No.	Welding current	Groove design	Filler rod
1	120	V	ER304L
2	120	U	ER308L
3	120	V&U	ER309L
4	150	V	ER308L
5	150	U	ER309L
6	150	V&U	ER304L
7	180	V	ER309L
8	180	U	ER304L
9	180	V&U	ER308L

Table 3.Design of experiment as per Taguchi method

2.4 Specimen sampling

The specimens for impact testing, hardness testing and for measurement of width, penetration of weld bead were taken from the weld pads as schematically shown in fig. 4.

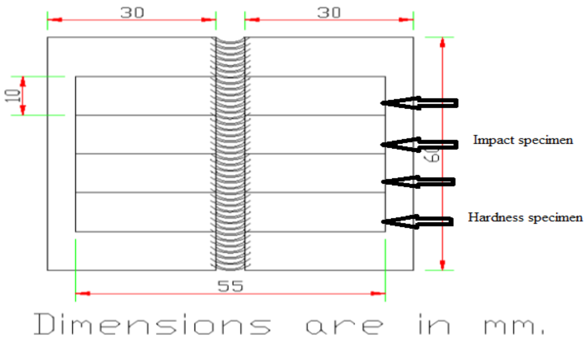

Figure 4.Specimen sampling

2.5 Impact test

TIG welded SS304L samples of 6 mm thickness are subjected to Izod impact tests at room temperature. The specimens with diamensions of 55mm*10mm*5mm.Three specimens from each welded plates were taken for impact testing. Average of these three impact values was taken. Impact test on the weld specimen was performed on the impact testing machine having a range of 0-30 Kgm or 0-300 joules.

Figure 5. Impact tested fractured specimens

2.6 Rockwell hardness test

Hardness was defined as the resistance of a material to plastic deformation usually by indentation. Before hardness test, we need to make smooth the surface of piece which we got after cutting. Then reading was taken at Base metal zone, Heat affected zone and Weld zone for each specimens.

Figure 6.Rockwell hardness machine

2.6 Aspect ratio

For achieve aspect ratio, we measure the width and depth of penetration of the weld bead with the help of vernier calipers of 0.01 mm least count. Each specimens finished finely and then after they were used to measure the width and penetrations and takes D/W ratio which gives aspect ratio.

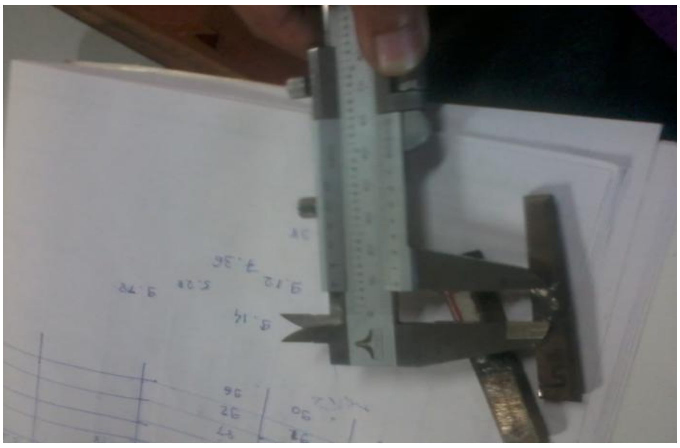

Figure 7.Vernier caliper for measuring depth and width

3. ANALYSIS OF VARIANCES (ANOVA)

The variable parameters welding current, filler rod and groove design were the influencing parameters to the impact strength, hardness and aspect ratio which was found by using ANOVA technique.

Ex. No.	Impact strength(Joules)	Hardness(HRB)	Aspect ratio
1	110	94	0.69
2	92	90	0.77
3	112	85	0.58
4	100	90	0.68
5	98	95	0.71
6	118	98	0.73
7	102	90	0.79
8	96	91	0.85
9	116	96	0.80

Table 4.Experimental observations

The percentage contribution of the welding parameters for impact strength, hardness and aspect ratio calculated were shown in table. Grand total sum of squares is given as the sum and square of each trail value. Sum of squares due to mean is given as the number of experiments multiplied by the square of the overall mean. The calculated total sum of squares is given as the difference between grand total sum of squares and sum of squares due to mean. Sum of squares for each parameter is given as 3[(A1-m)2 + (A2-m)2 + (A3-m)2] where, A1, A2, and A3 are the average value of each assigned parameters at levels 1, 2, 3 respectively. Degree of freedom (DOF) error is given by the difference between the DOF for the total sum of squares and sum of DOF for various factors. Mean square is given as the ratio of sum of squares due to each factor to DOF for each factor. Variance ratio is given by the ratio of mean squares due to the factor to mean squares error. Percentage of contribution is the ratio of sum of squares to the total sum of squares [6]. All the values for each parameter were calculated and shown.

Input parameter	DF	Sum of square	Mean Square	F	P
Welding current	2	0.889	0.445	0.02	0.0012
Groove design	2	603.556	301.778	13.06	0.8660
Filler rod	2	46.22	23.11	1	0.0663
Error	2	46.22	23.11	1	0.0663
Total	8	696.89			

Table 5.ANOVA for impact strength

Input parameters	DF	Sum of square	Mean Square	F	P
Welding current	2	32.89	16.45	0.53	0.2592
Groove design	2	4.22	2.11	0.07	0.0332
Filler rod	2	28.22	14.11	0.46	0.2224
Error	2	61.55	30.778	1	0.4851
Total	8	126.88			

Table 6.ANOVA for hardness

Input parameters	DF	Sum of square	Mean Square	F	P
Welding current	2	0.0078	0.0039	5.53	0.5798
Groove design	2	0.0088	0.0069	1.64	0.1702
Filler rod	2	0.0072	0.0112	1.35	0.1401
Error	2	0.0072	0.0036	1	0.1401
Total	8	0.0514			

Table 7.ANOVA for aspect ratio

4. RESULTS AND DISCUSSION

Results and discussions of the experimental findings of the welded joints prepared at constant voltage, welding speed, electrode size and single pass TIG welding. The welded specimens prepared under varying welding current, different filler rod and varying groove design. Effect of different variables on the each responces were discussed here.

4.1 The Effect of Welding current on Impact strength

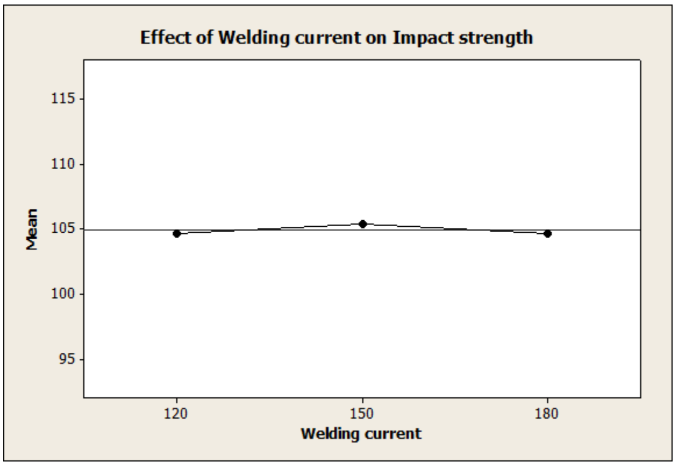

Figure 8. Effect of Welding current on Impact strength

The mean plot of the impact strength readings show that when current increases from 120 A to 150 A, impact strength going to increase but after increases current from 150 A to 180 A, it shows decrement in impact strength. At 150A current, impact strength is higher compare to other levels of current.

4.2 The Effect of Groove design on Impact strength

Groove design is the most influencing parameter to the impact strength. The mean plot shows that the highest impact strength obtained for V&U groove design and lowest value for U groove design. For V groove design, average value is obtain.

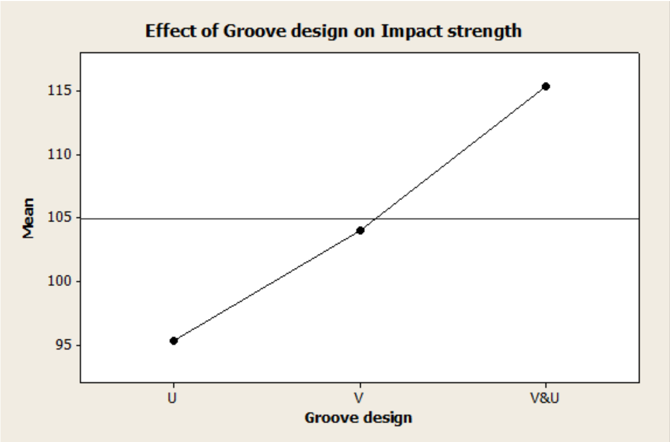

Figure 9. Effect of Groove design on Impact strength

4.3 The Effect of Filler rod on Impact strength

Mean effect plot shows that ER304L filler rod has higher impact strength and lower impact strength for ER308L filler rod. For ER309L filler rod, impact strength value is between the previous two filler rod impact strength value. Filler rod is the second influencing parameter to the impact strength, which can be conclude from ANOVA results.

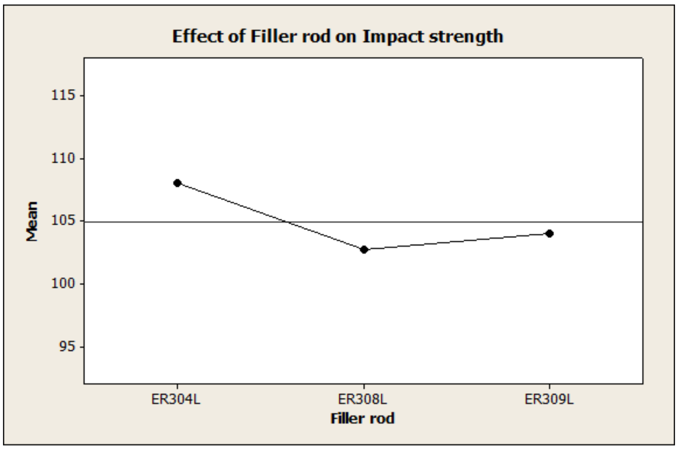

Figure 10. Effect of Filler rod on Impact strength

4.4 The Effect of Filler rod on Hardness

Mean effect plot shows that ER304L filler rod has higher hardness and lower hardness for ER309L filler rod. For ER308L filler rod, average hardness value is obtain. Filler rod is the second influencing parameter to the hardness, which can be conclude from ANOVA results.

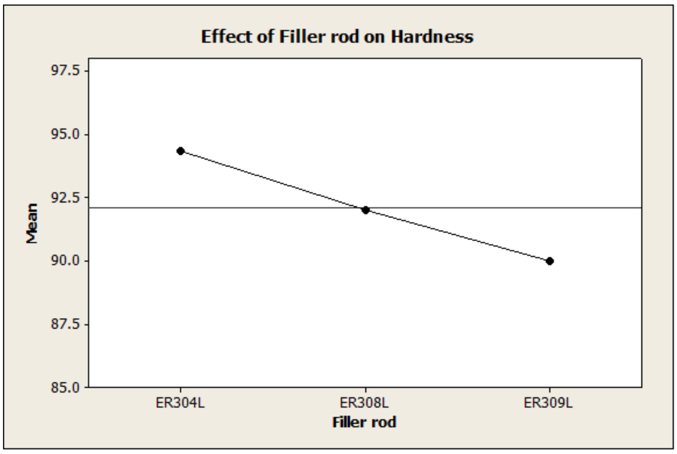

Figure 11. Effect of Filler rod on Hardness

4.5 The Effect of Welding current on Hardness

Welding current is the most influencing parameter to the hardness. Maximum hardness is achieve for 150 A Welding current. Welding current increases from 120 A current to 150 A, hardness increases but further increment in current, the hardness would be decrease. From the plot, it can be concluded that 150 current range is the best for higher hardness achievement.

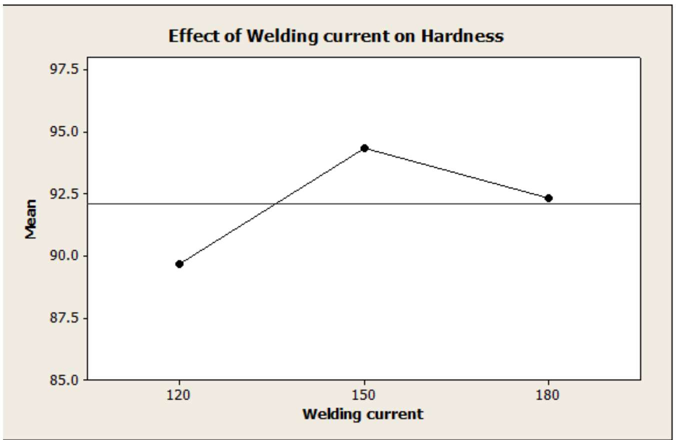

Figure 12. Effect of Welding current on Hardness

4.6 The Effect of Groove design on Hardness

The mean plot shows that the highest hardness obtained for V&U groove design and lowest value for V groove design. For U groove design, average value is obtain. From the ANOVA result, groove design shows negligible effect on hardness.

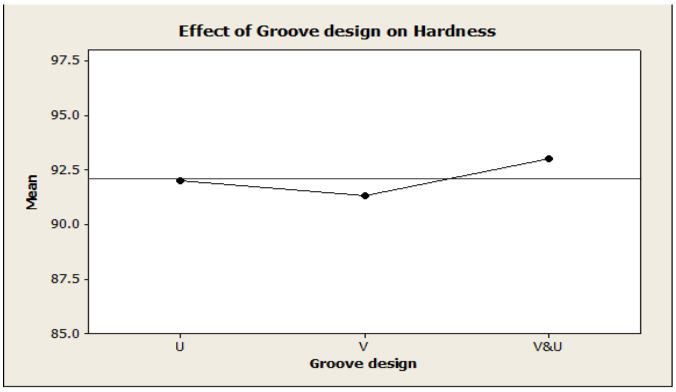

Figure 13. Effect of Groove design on Hardness

4.7 The Effect of Groove design on Aspect ratio

The mean plot shows that the highest aspect ratio obtained for U groove design and lowest value for V&U groove design. For V groove design, average value is obtain. From the ANOVA result, groove design is second influencing parameter to the aspect ratio after welding current.

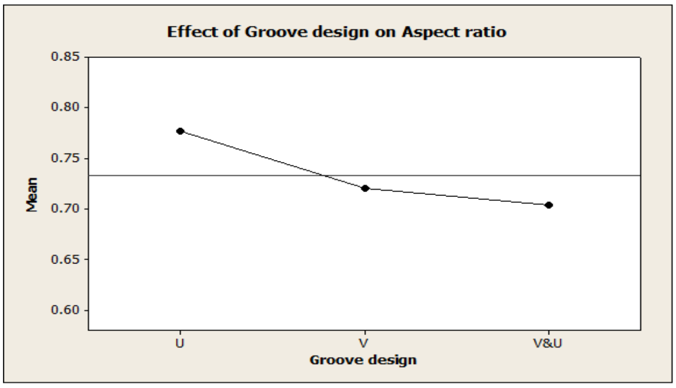

Figure 14. Effect of Groove design on Aspect ratio

4.8 The Effect of Welding current on Aspect ratio

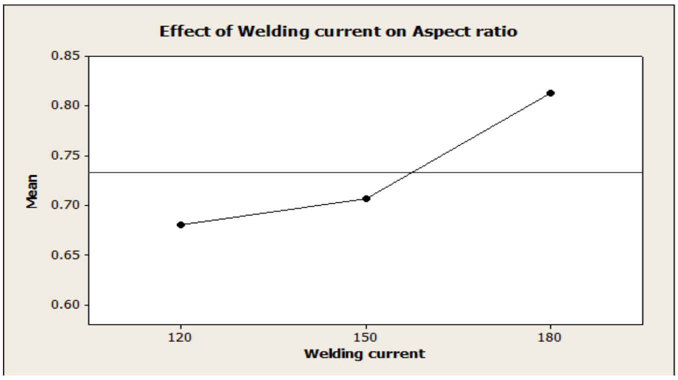

Figure 15. Effect of Welding current on Aspect ratio

Welding current is the most influencing parameter to the Aspect ratio. Maximum aspect ratio is achieve for 180 A

Welding current. Welding current increases from 120 A current to 180 A, aspect ratio increases. Welding current increases the melting rate of filler rod. So higher current leads to increment in melting rate which increases the width and depth of weld bead and finally aspect ratio also.

4.9 The Effect of Filler rod on Aspect ratio

Mean effect plot shows that ER304L filler rod has higher aspect ratio and lower aspect ratio for ER309L filler rod. For ER308L filler rod, average aspect ratio is obtain. Filler rod has negligible effect on aspect ratio which can be conclude from ANOVA results.

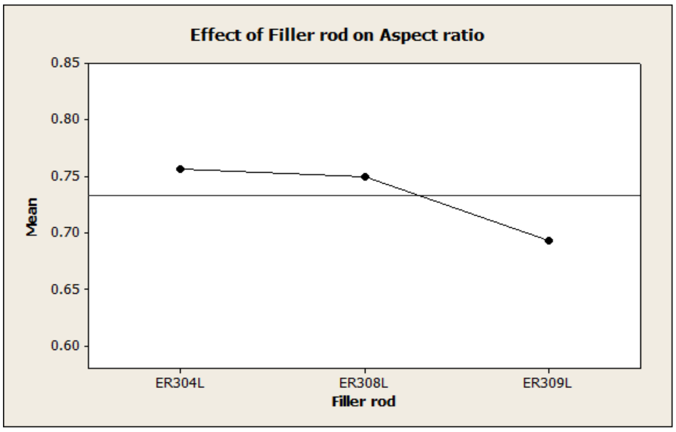

Figure 16. Effect of Filler rod on Aspect ratio

5. CONCLUSION

- It has been observed that welding current is the most influencing parameter for hardness and aspect ratio and groove design is mostly affect to impact strength.
- Analysis of variance confirms that 150 A current range, V&U groove design and ER304L filler rod(Ex.No.6)parameters are used for welding the SS304L Plate of 6mm thick, then highest impact strength and hardness can be achieve which also match with our experiment result.
- Analysis of variance also shows that for 180 A current range, ER304L filler rod and U groove design, the highest aspect ratio can be achieve.
- Finally present study conclude that 150 A current range, ER304L filler rod and V&U groove design are best parameters for achieving improved responces like impact strength, hardness and aspect ratio.

References

[1] Jay J Vora , Vishvesh J Badheka, " Experimental investigation on mechanism and weld morphology activated TIG welded bead-on-plate weldments of reduced activationferritic/martensitic steel using oxide fluxes" , Journal of Manufacturing Processes ,2015,356,1-10.

[2] Kamal Dhandha, Vishvesh J Badheka" Effect of activating fluxes on weld bead morphology of P91 steel bead-on-plate welds by flux assisted tungsten inert gas welding process. "Journal of Manufacturing Processes,2015,17,48-57.

[3] Navid M., Norizah Redzuan, Norhayati Ahmad, Tang Nan Hor,"Effect of Current on Characteristic for 316 Stainless Steel Welded Joint Including Microstructure and Mechanical Properties", Procedia CIRP ,2015 ,26, 560 – 564.

[4] Sakai.p.r.,"Comparison of Mechanical and Microstructural Characteristics in Maraging 300 Steel Welded by three different processes: LASER,PLASMA and TIG", Procedia Engineering, 2015 ,114, 291 – 297.

[5] Zhu.Li., " Effect of heat input on cryogenic toughness of 316LN austenitic stainless steel NG-MAG welding joints with large thickness", Materials and Design,2015,86,160–167.

[6] P.Bharath, V.G. Sridhar, M. Senthil kumar "Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique", Procedia Engineering ,2014 ,97,881 – 891.

[7] Ramesh kumar, N.Chauhan , P.M. Raole " Mechanical properties and microstructural investigations of TIG welded 40 mm and 60 mm thick SS 316L samples for fusion reactorvacuum vessel applications.", Fusion Engineering and Design ,2014,89,3149–3158.

[8] V.Anand rao, Dr.R.Deivanathan, "Experimental Investigation for Welding Aspects of Stainless Steel 310 for the Process of TIG Welding.", Procedia Engineering ,2014 ,97,902 – 908.

[9] G. Magudeeswaran , S. R. Nair , L. Sundar , N. Harikanan "Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds.", Defence Technology ,2014,10, 251-260.

[10] Yashar.Javadi, "Ultrasonic stress evaluation through thickness of a stainless steel pressure vessel", International Journal of Pressure Vessels and Piping, 2014, 123-124, 111-120.

[11] T.Sakthivel, "effect of the joining process on the accumulation of creep deformation and cavitation across the weld joint by 316L(N) stainless steel.", Procedia Engineering, 2013 ,55, 408 – 413.

[12] G.R. Mirshekari, "Microstructure and corrosion behavior of multipass gas tungsten arc welded 304L stainless steel", Materials and Design, 2015, 55, 905–911.

[13] S.Nair, "Experimental Investigation Of Multipass TIG Welding Using Responce Surface Methodology", international journal of mechanical engineering and robotics research, Vol. 2, No. 3, July 2013.

[14] Subodh kumar "Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints",Materials and Design,2011,32,3617–3623.