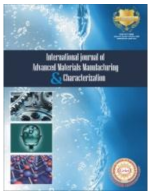

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Distortion Control in TIG Welding Process with Taguchi Approach

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ABSTRACT

Tungsten Inert Gas (TIG) welding is a widely applied manufacturing process. The weld distortion is one of the major constraints which can not be completely avoided irrespective of material type and thickness. The present paper reports the optimization of weld process parameters with Taguchi approach for the transverse distortion control applied to MS structures of 3 mm thickness with TIG weld process. ANOVA is applied for the optimization of weld parameters control. In this study the transverse distortion of TIG, welding process was evaluated using weld current, root gap, Argon gas flow rate and the weld speed as the main parameters. A L8 orthogonal array was selected for the design of experiments towards the distortion optimization caused by butt welding. It was found from these experiments that Root gap has a major contribution of 43% and Weld current of 36% influence on distortion. Robust design is possible by controlling these parameters and identifying their criticality in process with respect to pooled errors in experiments. Pooled errors include effect of parameters which do not have appreciable contribution towards distortions.

Introduction

Tungsten inert gas welding, TIG is widely applied in manufacturing process for different types of materials like Aluminum, Mild steel (MS) and different type of stainless steel alloy grades. The optimization of TIG welding process parameters play important role for the final product quality in terms of weld distortions, joint efficiency and mechanical properties. As welding process involves the heating and cooling process in non uniform manner, the distortions are unavoidable. The weld process contributes to the development of several kinds of distortions like longitudinal, transverse or angular distortions [1]. In addition, form of residual stresses also develops in the structure if the process is not optimized with weld process parameters. The welding process parameters like weld current, voltage, shielding gas, weld speed, root gap, gas flow rate etc. are having combined effects. In order to select the typical process parameters optimization, a Taguchi method is applied for the welded samples distortion measurements [2, 3]. The process parameter optimization in TIG weld process with stainless steels [4], aluminum alloy [5] and titanium materials [6] were attempted with Taguchi method by various researchers extensively. Taguchi method is one of the best practical technique which offers the effective selection process parameters with minimum number of experiments. SMAW weld process parameters and weld bead geometry optimization with different materials was carried out with Taguchi method [7,8,9]. Extensive research was carried to analyze the weld bead geometry and optimization with selection of various process parameters in Laser welding with similar and dissimilar materials joining process with Taguchi method of experimental design [10-13]. Multiple process input parameters and output parameters with super austenitic steel with CO2 laser welding with different shielding gases at single input power were explored with Taguchi method of Design of Experiments [14]. The effect of shielding gas and weld speed in terms of minimum weld defects analysis are optimized with Diode Laser welded samples of Ti6Al4V with Taguchi method intuitively and are well validated by statistical methods with Artificial Neural Networks [15]. Friction Stir welding process parameters are optimized for different types Aluminum alloys joining with Taguchi method with multiple input parameters and selected output parameter by adapting suitable statistical methods are frequently reported [16,17,18].The welding process produces some unavoidable distortions even though care has been taken for the best process output. The selection of pulsed TIG weld process parameters for

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joining Aluminium alloy for maximizing the mechanical properties like tensile strength (UTS) and hardness as weld quality assessment quantities are examined with Taguchi approach by using analysis of variance called ANOVA [19] The temperature distribution and weld pool simulation was provided predicting the thermal cycle and also provides an estimate of the depth of weld penetration, the geometry of the weld pool and the cooling rates. Both 2D and 3D finite-element models have been developed using the solution of heat-transfer equations and validated with experimental results[20]. The studies for control of parameters towards the transverse shrinkage and angular distortion are reported in details along with other output parameters like tensile strength and weld bead geometry in a detailed way [21]. The prediction methodology towards angular distortions with multipass GMA welding process were carried out with mathematical models to simulate the process parameters and studied with welded stainless steel structures [22]. The welded plate distortions in terms of transverse shrinkage and angular distortion as two output parameters are explored with radial basis function neural network model by using six input parameters in a pulsed metal inert gas welding process for understanding the model for prediction of distortions [23, 24].

The present work is aimed to study the influence of TIG process parameters and their optimization for the transverse distortion control as main output parameter. The weld process parameters optimization with weld distortion as one of the output parameter using Grey analysis of Taguchi method was reported in [21]. However, the weld process control parameters optimization with Taguchi method towards weld distortion studies has been rarely reported in the literature.The purpose of this work is to optimise the TIG weld process parameters in terms of weld distortion as major output and by keeping variable input parameters with Taguchi method. The simple parametric variation with minimum number of experiments is aimed and factors with two level design of experiments are implemented. The effect on weld distortion control with four independent input parameters namely weld current, Argon gas flow rate, root gap and the weld speed are selected as control factors and distortion as output parameter. Two level experiments were carried out as this is a preliminary process study and not a tolerance design of a productivity optimization. Similarly, signal to noise ratio is not considered as the objective was not to reduce the process variation. Interaction between the process parameters Current and Argon gas flow rate is considered for the evaluation of the individual contribution of weld process parameter for the distortion. The percentage contribution of these parameters for controlling the welding process to minimize the distortions is presented.

TIG welding process

TIG welding is a process which uses the heat of electric arc between the non-consumable Tungsten electrode and work piece for melting of faying surfaces and inert gas is used for shielding the arc zone from atmospheric gases. TIG welding is widely used for welding of metals like stainless steel, some alloy grades of Aluminium, Mg materials. It is used in critical applications like for precision welding in nuclear structural materials fabrication, air craft, chemical, petroleum, automobile and space craft industries. The Tungsten arc process is being employed widely from the precision joining of critical components which require controlled heat input. The small intense heat provided by the Tungsten arc is ideally suited to the controlled melting of the thin sheets, some times without filler rods. Advantages of TIG welding are concentrated arc, no slag, no splatter, little smoke or fumes, good weld penetration, preferred for stainless steel alloys. Disadvantages are slow process, good skill requirement for manual operation.

Control of weld Distortion

If distortion is to be prevented or minimized in a weldment, strategies must be used in the design and in shop practices to overcome the effects of the heating and cooling cycles. Shrinkage or contraction cannot be prevented, but it can be controlled [1]. Departure from initial dimensional specifications in a fabricated structure or component as a consequence of welding is called welding distortion. Welding involves highly localized heating of the metal being joined together to cause melting of base metal and rejoining with recrystallization of grain structure of base material. The temperature distribution in the weldment is therefore non uniform. Normally, the weld metal and the heat affected zone (HAZ) are at temperatures substantially above that of the unaffected base metal. Upon cooling, the weld pool solidifies and shrinks, exerting stresses on the surrounding weld metal and heat affected zone. Several types of distortion can occur in joining metals due to longitudinal shrinkage, transverse shrinkage, angular distortion, fillet distortion, neutral axis distortion [1]. The pictorial representation as mentioned in Figure 1 shows that the shape of the components modify due to distortion in longitudinal, along the length of the weld and in the transverse, perpendicular to weld direction. Transverse distortion can be measured as the distortion angle measured from weld point as angular distortion.

In the present reported work, transverse distortion is measured and expressed in angular distortion in degrees. If a component were uniformly heated and cooled, distortion would be minimized. However, welding locally heats a component and the adjacent cold metal restrains the heated material. This generates stresses greater than yield stress causing permanent distortion of the component. Some of the factors that affect distortion are kind of restraint, amount of restraint, welding procedure, properties of parent metal etc. Because welding involves highly localized heating of joint edges to fuse the material, non-uniform stresses are set up in the component because of expansion and contraction of the heated material. As shown in Figure1, distortion causes change in shape and orthogonal reduction in length, shrinkage in both longitudinal and transverse direction. The front view of welded component shows the transverse distortion which is an angular movement of the part about the weld point.The smaller parts considered in this report result in a linear angular movement which is the response considered in this study. Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion process of the hot metal (heat affected zone) adjacent to the weld pool. However, tensile stresses occur on cooling when the contraction of the weld metal and the immediate heat affected zone is resisted by the bulk of the cold parent metal. The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature.

Taguchi method for experiments

The selection of weld process parameters for the best weld sample production and weld quality are very important. As the number of parameters are increased the cost and experimentation procedures get added up. The accuracy of welding and defect free samplesproduction processis difficult to achieve with a full factorial experiment. The alternate method of simple experimentation was suggested by Taguchi which is well established in Industry in Japan and subsequently spread to the world and is a preferred method in TQM or Six Sigma companies [3,23]. Taguchi method uses a special design of experiments called Orthogonal Arrays. It gives a statistically equivalent full factorial study of the entire parameter range with minimum number of experiments. In addition, it also evaluates the interaction of main parameters in changing the output response variations. This method has become popular in industry as it is feasible to evaluate, optimize and control the mean & variation in production processes.The study is called off line if optimization is done as part of planning at the time of process design and on line if optimization is done for process improvement. The first step in Taguchi process is to do two level factors experiments to see the control parameters, called system design. System Design leads to understanding the contribution of critical parameters within the process, feasible levels of control factors, are obtained as was aimed in the present study. This stage is a cost effective accurate study with analysis of Variance, ANOVA of Parameters to know the factor contribution for variation percentage compared to the errors. Once the control factors are fixed the next step is to obtain robust design which controls the process inspite of external factors at this stage inner array control factors and external array uncontrollable Noise factors are taken and Parameter Study is done. Analysis of Variance is done with S/N ratio, Signal to Noise ratio, to control process variation against external factors making the performance robust. The third stage of control is Tolerance Design. Whereas three level factor experiments are done to take advantage of the non linearity in variation. This fine understanding of non linearity effect helps in specifying tolerance to parameters. Two level factors have one DOF & three level factors have two DOF. The process is applied for the number of experiments as per Design of Experiments, DOE. Taguchi has given Orthogonal Arrays, OA, experiments for factors which vary at two levels. Every factor can take two levels in the process and the variation is studied as the combined effect of the main factors and also with their interactions.

In the present experimental study special attention is given towards the weld distortion control optimization with factors with two levels. Taguchi L8 experiments were conducted, with Weld current, Argon gas flow rate, root gap and weld speed were the main factors selected as System Design. In addition, weld current and Argon gas flow rate interaction was also selected for this study.

Weld samples development

TIG welding was carried out with MS samples of 200 mm X 50 mm X 3 mm of each and the final sample with size of 200 mm X 100 mm X 3 mm. The MS plates were prepared with V grove design (groove angle of 60^0)and butt weld conditions with single pass filler wire. The distortions are observed in all the samples and are measured with dial gauge fitted to a height gauge. Tungsten Electrode was connected to the Negative charge of the DC hence, Tungsten Electrode Negatively connected, called EN type welding. The current variation was 50 to 60 Amps and the voltage was controlled at 11V. The filler material used was ER70S2 a carbon steel filler rod of 1.5 mm diameter, prescribed for MS base material. The Butt welding gap is due to the root gap provided. The process was stabilized to minimize the variation due to uncontrolled parameters or manual error bias. The Welding machine used was a Weldman EJM 300 TIG, an AC/DC, 3 Phase, 50 Hz, pulse controlled dual, TIG & MAG welding machine capable of welding 0.8 mm to 19 mm thick plates. The two plates placed with the root gap at the bottom and the angle provides a V groove for the weld bead. The weld bead will be the rectangular area of root gap and plate thickness, triangular bead area of V groove and the top bead chord area. The welded sample developed with TIG welding with MS plates are shown in Figure 2 during the distortion measurement analysis for reference purpose. The weld process parameters which are used as main factors are mentioned in Table 1 with details and rest other parameters are kept same through out the experiments.

Design of experiments, results and discussion

Genichi Taguchi has used the design of experiments effectively to improve quality, productivity, reliability, and cost and is extensively used in industry as a tool in their TQM or Six Sigma activities [23]. The use of Orthogonal Arrays, in this study, an L8 experiment, was done is a fractional factorial methodology, which is statistically proven to give the results of a full factorial experimentation. L8 has designed 8 unbiased experiments which have been conducted randomly, not in 1 to 8 sequences to remove the experimental bias. The control factors are allotted to the columns as shown in Table 2. Four factors, Weld current, gas flow rate, root gap and speed of welds were allotted to the columns, 1, 2, 4 & 5 respectively. Each of these factors has two levels of possible values and they are assigned to form the orthogonal experimentation. Column 3 is assigned to evaluate the interaction of Current and Argon flow rate. Columns 6 with title error 1 and column 7 with title error 2, had no assigned factor and represent the change in response due to experimental errors. The main effect of the factors is calculated by analysis of variation called ANOVA. The output distortion is expressed in degrees of distortion, an angular unit obtained from Trigonometry of the measured values.

In Table 3 the seven possible factors (main, interaction and error) are shown in column 1. Process parameters in column 2 are the sum of squares (SS) of the variation due to each of the assigned factors, which is the variation that is due to the two levels of the factor. For example as the current varies from 55 A to 60 A the sum of squares is 2.42. Similarly other SS are calculated. The 3rd column is degrees of freedom (DOF). This is how independently the factor represents the outcome of distortion response, one for a two level factor. The 4th column is the variance which is SS/DOF for each factor, a measure of variation. However, for relative merit of the effect on variation, percentage contribution, P, for each factor is calculated and is given in the 5th column. The error sum of square (SS) occurs due to the experimental variation. Also, it indicates how well the selected factors are influencing the output parameter.

To improve the accuracy of prediction the error contribution is added to the noncontributing parameters here weld current and gas flow rate interaction and the main effect of gas flow rate. The percentage contribution with respect to the total sum of squares (SS) and a more meaningful Pooled ANOVA is calculated and shown in Table 4. In this Table 4, non contributing factors from ANOVA of Table 3 are taken as error factors from the estimate of their percentage contribution P. Factors with less contribution say P less than 5 are added to the error to get the pooled ANOVA of Table 4. Factor B, Argon Flow rate, P = 0.0204; Interaction factor, C, has P value of 1.65; These two factors are combined with the error factors F error 1 and factor G error 2 and the combined error factor in pooled ANOVA has a P value of 6.0. This higher value improves the estimate of contribution of critical factors.As mentioned in Table 4, it represents Pooled ANOVA,three factors have contributed to the distortion of parts due to welding, factor A, weld amps contributes P = 36.92 %, factor B root gap has a contribution P = 43.25 % and finally, the speed of weld contributes P = 13.83 %. These three are identified as critical factors to the welding process and needs to be specified with close tolerance and controlled critically to obtain a robust weld process.

Another, graphical, representation of L8 experimental results, called linear graphs with representation of distortion with two levels of each factor, are shown. This representation provides a visual selection of best level are shown in Figure 3 to Figure 7. A is desired to be minimum, in the graphs level which result in lower values of distortion is identified as the optimum value for that factor. For the main effects, current in Figure 3, Level 1(L1) is preferred; Weld speed effect seen in Figure 4, Level 2 (L2) is preferred. Argon gas flow effect in Figure 5, no significant effect on welding distortion and hence it is not a control parameter the level at which continuous shielding is provided is to be given, level can be decided for process ease and cost effectiveness. The effect of root gap is shown in Figure 6 which gives a higher level 2 (L2) as optimum to reduce distortion. Lastly, as per shown in Figure 7 gives the interaction of weld current and gas flow rate on distortion has no significant effect and need not be considered as important. In some processes the main factors are not critical but the interaction becomes significant. Whenever a designer feels an interaction could have an effect he can include the interaction as a parameter. These graphs will give a quick visual status of the effect of the levels of the factors in causing distortion of parts during welding.The requirement is to have minimum distortion of the part after weld and we look for those levels in the graphs which will become the levels to be maintained to obtain the optimized process.Using Taguchi experiments we could select the factors which are important in controlling the distortion to a lower level and also specify the level which is optimum and finally the importance of this factor is quantified by the percentage contribution that it has in the output parameter level.

Conclusions

The TIG welding process parameters are selected by using Taguchi method of experimentation with minimum number of experiments. L8 orthogonal array was selected and factors with two levels were used in the design of experiments. ANOVA is developed and implemented for the experimental data for control of selected parameters. This is the simplest case for the weld distortion analysis for optimum TIG process parameters control with lowest number of experiments. In addition critical contribution of weld process parameters is further analysed with Pooled ANOVA. The experiments on distortion control of weld parameters for TIG welding for MS structures have resulted with effect of each parameter contributions as following manner.

- Root gap contributes 43 %.
- Weld current contributes 37 %.
- Weld speed contributes 14 %.
- Parameter Gas flow rate and Interaction of current and gas flow rate has no major effect and are combined with the error and the pooled error is about 6 %.

This procedure can be effectively used to reduce weld distortion in the design of structures with TIG welding process and the optimization with the various input parameters.

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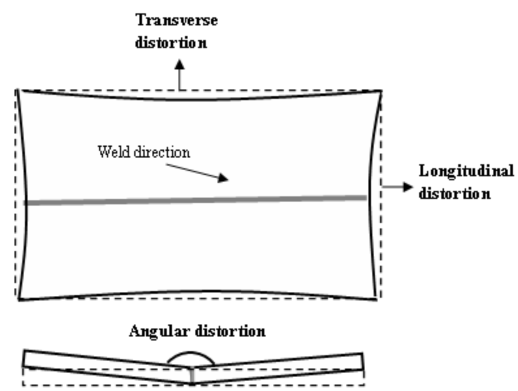

Figure 1. Distortions caused by welding.

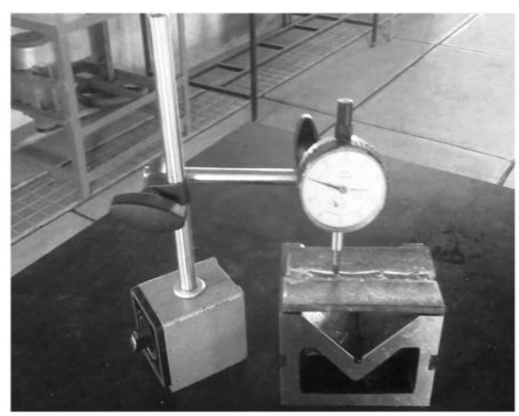

Figure 2. Measuring distortion on welded part

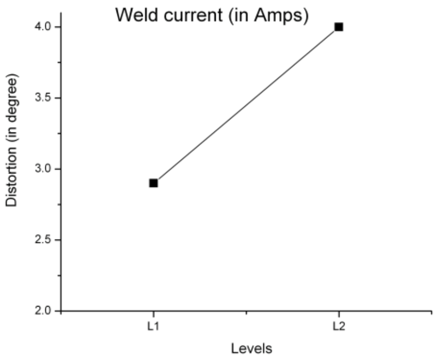

Figure3. Weld current affect on distortion.

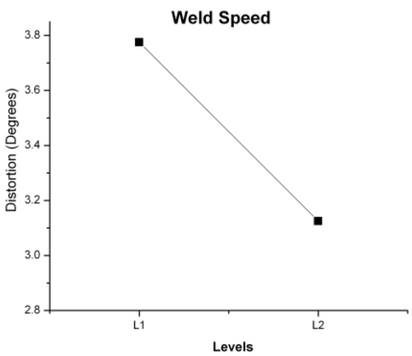

Figure 4. Weld speed affect on distortion

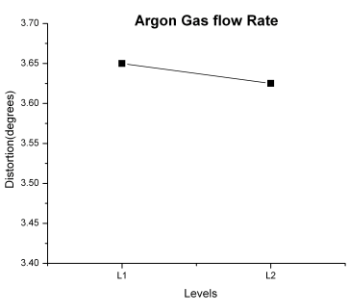

Figure 5. Argon gas flow affect on distortion

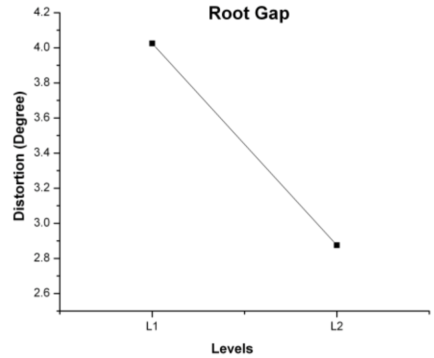

Figure 6. Root gap affect on distortion.

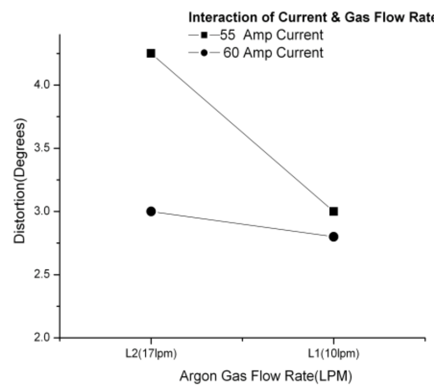

Figure 7. Interaction affect on distortion

Table 1. Major Process parameters for TIG welding

S.No	Process parameters	Units	Level 1 (L1)	Level 2 (L2)
1	Weld Current	Amps	55	60
2	Argon Gas flow rate	LPM	10	17
3	Root gap	mm	1.5	2
4	Weld speed	mm/s	1	2
5	Weld Voltage	Volts	11	11

Table 2. L8 Orthogonal array experimental lay out

Factor	Weld current (Amp)	Argon Flow rate (LPM)	Amp_ Argon Flow	Speed (mm/sec)	Root gap (mm)	Error1	Error2	Distortion Degrees
	A	B	C	D	E	F	G	y
Trials	1	2	3	4	5	6	7	
1	55	10	1	1	1.5	1	1	3.6
2	55	10	1	2	2	2	2	2
3	55	17	2	1	1.5	2	2	4
4	55	17	2	2	2	1	1	2
5	60	10	2	1	2	1	2	4
7	60	17	1	1	2	2	1	3.5
8	60	17	1	2	1.5	1	2	5

Table 3. Analysis of Variance, ANOVA

ANOVA					
Col	Parameter	SS	DOF	V(Variance)	P
1	A(Weld current)	2.42	1	2.42	39.575
2	B(Argon Flow rate)	0.00125	1	0.00125	0.0204
3	C(Amp vs Argon flow rate)	0.10125	1	0.10125	1.6558
4	D(Speed of weld)	0.845	1	0.845	13.818
5	E(root gap)	2.645	1	2.645	43.254
6	F(error1)	0.00125	1	0.00125	0.0204
7	G(error2)	0.10125	1	0.10125	1.6558
	Total (SST)	6.115			

Table 4. Pooled Analysis of Variance

ANOVA Pooled					
Col	Parameter	SS	DOF	V(Variance)	P
1	A(Weld Amps)	2.26	1	2.26	36.92
2	B(Root Gap)	2.65	1	2.65	43.25
3	D(Speed of weld)	0.85	1	0.85	13.83
4	Error (pooled)	0.37	4	0.09	6.00
	Total	6.12	7		100

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