Analysis and Optimization of T Joint Argon gas welding process parameters for Stainless Steel AISI 310

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Abstract - *Welding is manufacturing process which creates permant joint by fusing of the surface of the part to be joined together. It is widely used in automobiles, construction, industries, etc. for various purposes. So it is important to analyze strength of welding joint and how it will be increased by varying it`s process parameter like voltage, welding speed, feed rate etc.Catia software used to model T joint , meshing and FEA analysis carried out by using ANSYS package joined for software analysis. Experimental analysis carried out by using strain gauge for measuring strain value and UTM for applying gradual load. Results will validate by comparative analysis using FEA and Strain gauge values.*

Experimental and FEA correlation conclude that T joint are made stronger by varying process parameter of the welding.

***Key Words*: FEA, UTM, AISI 310, T joint, welding**

1. INTRODUCTION

Welding is process of fusing multiple pieces of metal together by heating filler metal to liquid state. Welding is applicable to iron base materials. Stainless steel are the engineering material and is applicable in the all the fields. They exhibit excellent corrosion resistance, high strength and fabrication characteristics. They are preferred over other material for welding only because of their performance in any environment and they can be fabricated by most of fabrication techniques. Welding of stainless steel provide optimum corrosion resistance and strength. GMAW has higher electrode efficiencies, usually between 93% and 98%, when compared to other welding processes.

Stainless steel are used in fluidized bed combustors, kilns, radiant tubes, tube hangers for petroleum refining and steam boilers, coal gasified internal components, lead pots, thermo wells, refractory anchor bolts, burners and combustion chambers, retorts, muffles, annealing covers, food processing equipment, cryogenic structures. Components of Blowers, turbine are exposed to corrosive, abrasive, and other damaging influences, which cause them to crack, pit, erode, and otherwise degrade generally at welding joints. Turbine and compressor blades are among the most commonly repaired of these parts and can be restored multiple times to significantly extend their useful life.

The experimental optimization of any welding process is often a very costly and time consuming task, due to many kinds of non-linear events involved. One of the most.

Widely used methods to solve this problem is the response surface methodology (RSM), in which the experimenter tries to approximate the unknown mechanism with an appropriate empirical model, being the function that represents it called a response surface model. Identifying and fitting from experimental data a good response surface model requires some knowledge of statistical experimental design fundamentals, regression modeling techniques and elementary optimization Methods. Response Surface Method technique is effective for various welding technologies in investigating the effect of process parameters on weld quality in terms of weld bead geometry and mechanical properties. Again, the effect of influential welding parameters depends largely on several factors such as material type, joint type, as well as welding process involved and has to be researched separately for each new component, material as well as welding process. Moreover, various mathematical models developed by using this technique are found fairly accurate in predicting weld-bead geometry and mechanical properties and optimizing the welding conditions.

2. LITERATURE REVIEW

A literature review is conducted on welding process and the findings of the same are presented below,

Dhasharat Ram, (2004) has studied stages of development of the model, design of experiments and optimization of parameters using Analysis of Variance (ANOVA). Experiments have been conducted using Taguchi L9(34) orthogonal array considering four input parameters- welding speed, accelerating voltage, beam current, distance between gun to work. The performance of EBW was measured in terms of weld strength and weld penetration levels. Two sets of nine experiments were conducted to predict the performance of the model. Test specimens were machined to the required accuracy levels using CNC Wire-cut Electro Discharge Machine. The weld penetration was measured using NDT methods. Researcher investigated the influence of the weld parameters on weld strength and weld penetration. Researcher had compared the results of the regression model with the experimental results. Researcher concluded optimum condition of welding as accelerating voltage of 50kV, beam current of 60mA, and weld speed of 1m/min and distance between guns to work of 200mm.

Davi Sampaio Correia, (2005) has done the optimization of a GMAW welding process using response surface methodology. The situation was to choose the best values of three control variables (reference voltage, wire feed rate and welding speed) based on four quality responses (deposition efficiency, bead width, depth of penetration and reinforcement), inside a previous delimited experimental region. For the RSM, an experimental design was chosen and tests were performed in order to generate the proper models. In the GA case, the search for the optimal was carried out step by step, with the GA predicting the next experiment based on the previous, and without the knowledge of the modeling equations between the inputs and outputs of the GMAW process. Results indicate that both methods are capable of locating optimum conditions, with a relatively small number of experiments. Researcher concluded that the RSM technique found a better compromise between the evaluated responses than the GA.

K.Y. Benyounis et al, (2008) investigated the tensile strength and impact strength along with the joint-operating cost of laser-welded butt joints made of AISI 304. The relationships between the laser-welding parameters such as laser power, welding speed and focal point position and the three responses like tensile strength, impact strength and joint-operating cost were established. Researcher found that welding speed is the most effective parameter in the optimization of response output parameters.

H. Naffakh et al, (2010) investigated characteristics of dissimilar metal weld between AISI 310 and Inconel 657 alloy. These two dissimilar welds are joined together with 75 degree V groove with the help of argon tungsten welding. Welding process is carried out using different filler metal along with GTAW and SMAW. It is found that Inconel A and Inconel 82 weld metals are the best choices for the dissimilar welds of AISI 310 and Inconel 657.

Ugar soy et al (2011) investigated arc welding parameters for shielded metal arc welding method. To determine welding parameters national and international welding standards and also welding experience is taken into the consideration for shielded metal arc welding method. They examined the determined welding process parameter for shielded metal arc welding method and resultant ideal welding parameters and their limits are given in equations and tables.

Kwanwoo Kim et al, (2011) were studied pulsed laser welding using the commercial finite package MARC FE software and the simulated results were compared with empirical data. A 3D moving heat source representing pulsed Nd: YAG was designed as the heat input condition to the welding simulation. The temperature distribution and molten zone during welding were predicted through FE analysis for different power level.

Kassab, Henri (2012) analysed T joint with V groove for AISI 1018 steel plate. Experimentally and with finite element Method they had predicated deformations, distortions and residual stresses resulting from the welding of the Plates. Researchers found that welding quality can be improved by varying its input parameters such as current, voltage and torch speed.

Dalvi et al. (2012) did FEA Based Strength Analysis of Weld Joint for Curved Plates (Overlap) especially for Designing Pressure Vessel Skirt Support. They had studied by analysis and experimentation of 03 cases, for which they conducted 53 analyses. Analysis type for this was Structural Non Linear Finite Element Analysis by analysis three different conditions they had find the optimum overlap angle for curved plates used for the pressure vessel. From experiment it is found that with increase in overlap angle strength of welding increase.

Turkalj G. (2012) determined FEM stress concentration factor for fillet welded CHS plate T joint. Researcher modelled fillet welded T-joints with FEM and analysis of finite element mesh is conducted. Stress concentration factors calculated by finite element model analysis were found to be higher than those interpolated from experimental data. C350LO AS 1136-1991 standard steel grades is used for the analysis purpose.

Mhetre, Jadhav S.G. (2012) developed an efficient and reliable method for simulation of the welding process using the Finite Element Method. Researchers have done the FEA simulation of welding process and validated with the experimental results for IS 1570 alloy steel material. Analysis results help researchers to understand the phenomena governing the welding of a joint, offering insight on the mechanisms and mechanical aspect particular to the welding process.

Essam et al. (2012) determined Stresses Distribution in Spot, Bonded, and Weld- Bonded Joints during the Process of Axial Load. The elastic-plastic stress distribution in weld-bonded joint, fabricated from austenitic stainless steel (AISI 304) sheet of 1.00 mm thickness and Epoxy adhesive Araldite 2011,subjected to axial loading is investigated. Complete 3-D finite element modelling and analysis of spot welded, bonded and weld-bonded joints under axial loading conditions is carried out. From experiment it is conclude that the failure of spot welding happened at the interface between weld-nugget and HAZ.

K.Ashok Kumar et al, (2012) have studied thermo-mechanical analysis of a corner welded joint by finite element method. During work a corner welded joint has been used by them to simulate the Arc Welding process for the purpose of estimation of distortion and residual stresses. The FEM has been carried in two stages. In the first stage, the pure thermal analysis is carried to estimate the time dependent temperatures. The temperatures obtained in thermal analysis are given as input in the second stage in which Structural Analysis is carried out. Researcher found that the maximum stresses are found in X-direction of the vertical plate in the corner joint.

Izzatul Aini Ibrahim et al, (2012) has studied the effects of different parameters on welding penetration, micro structural and hardness measurement in mild steel that having the 6mm thickness of base metal by using the robotic gas metal arc welding are investigated. The variables that choose for study were arc voltage, welding current and welding speed. The arc voltage and welding current were chosen as 22, 26 and 30 V and 90, 150 and 210 A respectively. The welding speed was chosen as 20, 40 and 60 cm/min. The penetration, microstructure and hardness were measured for each specimen after the welding process and the effect of it was studied. As a result, it obvious that increasing the parameters value of welding current increased the value of depth of penetration. Other than that, arc voltage and welding speed is another factor that influenced the value of depth of penetration. The microstructure has shown the different grain boundaries of each parameter that affected of the welding parameters.

M.M.A.Khan et al, (2012) has studied experimental design approach to process parameter optimization for CW Nd/YAG laser welding of ferritic/austenitic stainless steels in a constrained fillet configuration. Researchers has used response surface methodology to determine the optimal welding parameters, and developed a set of mathematical models relating the welding parameters to each of the weld characteristics. The quality criteria considered to determine the optimal settings were the maximization of weld resistance length and shearing force, and the minimization of weld radial penetration. Laser power, welding speed, and incident angle are the factors that affect the weld bead characteristics significantly. A rapid decrease in weld shape factor and increase in shearing force with the line energy input in the range of 15–17 kJ/m depicts the establishment of a keyhole regime. A focused beam with laser power and welding speed respectively in the range of 860–875 W and 3.4– 4.0 m/min and an incident angle of around 12° were identified as the optimal set of laser welding parameters to obtain stronger and better welds.

Yupiter et al. (2013) investigated welding sequence effect on induced angular distortion using FEM and experiments. During which they modelled the specimen of a combined butt and T joint geometry and simulated using Multipass Welding Advisor (MWA) in SYSWELD 2010 based on the thermal-elastic-plastic approach with low manganese carbon steel S3355J2G3 as specimen material. During the experiments they used GMAW Technique. The 3D thermo-elastic-plastic FEM analysis shows a good agreement with the experimental results with regards to weld distortion. Based on the results of experiment and simulation it is found that the first welded side shows more angular distortion than the later welded one.

Masumi, Vatani (2013) have developed an appropriate numerical model to predict the onset of the failure of a pipeline-wall during an in-service welding process. They had

Obtained thermo-mechanical stresses as well as the temperature across the pipe wall. For analysis they had used 316 stainless steel material pipes. A 3D FE based model has been developed to analyze the temperature fields. Maximum temperature during welding may become larger than the Sensitization Temperature of the 316 stainless steel and this increases the possibility of cracking.

Chandresh N. Patel (2013) researcher has studied design of experiment method for MIG and TIG welding process. Researcher has optimized the experimental data by using grey relational analysis optimization technique. Input process parameters were welding current, wire diameter and wire feed rate for MIG and TIG welding process. Material used during analysis was AISI 1020. AISI 1020 with material thickness of 5 mm with double v groove is used for the experimentation. For experimental design researcher has used full factorial method to find out number of readings. To find out percentage contribution of each input process parameter for obtaining optimum condition, he used analysis of variance method. Grey relational analysis is used for optimization of different values.

Palani.P.K, (2013) investigated the effect of TIG welding process parameters on welding of Aluminium-65032. Response Surface Methodology was used to conduct the experiments. The parameters selected for controlling the process are welding speed, current and gas flow rate. Strength of welded joints was tested by a UTM. Percent elongation was also calculated to evaluate the ductility of the welded joint. From the results of the experiments, mathematical models have been developed to study the effect of process parameters on tensile strength and percent elongation. Optimization was done to find optimum welding conditions to maximize tensile strength and percent elongation of welded specimen. Confirmation tests were also conducted to validate the optimum parameter settings.

The version 14 of the MINITAB software was used to develop the experimental plan for RSM. Researcher concluded that welding speed has most significant effect on both UTS and percentage elongation followed by welding current. However gas flow rate has least significant influence on both UTS and percent elongation.

Sr .No	Researcher	Material Used	Method Of Analysis	Type Of Joint	Type Of Welding
1	Hamed Masumi asl (2013)	316 S.S.	FEA, Numerical	T	-
2	Yupiter H.P. Manurung (2013)	S3355J2 G3	FEA	Butt, T	Argon
3	Chandresh N. Patel(2013)	AISI1020	Analytic	T	TIG
4	V.Lazica (2012)	EN100256	Analytic	Butt	Filler weld
5	Rabih Kamal Kassab (2012)	AISI-1018	FEA, Numerical	T	Filler weld
6	G.Turkalj (2012)	C350LO	FEA	T	-
7	Xiaocong He (2012)	SAEJ2340300Y	FEA	Butt	Argon,laser
8	Rajlaxmi N. Mhetre(2012)	IS 1570	FEA	T	CO2 ARC
9	Essam Al Bahkali(2012)	AISI (304)	FEA	Lap	CO2 ARC
10	Zhang Shenghai (2012)	10CrNiMnMoV	Analytic	Butt	TIG
11	Izzatul Aini Ibrahim(2012)	M.S.	Analytic	-	CO2 ARC
12	M.M.A.Khan (2012)	AISI 304 S.S.	Analytic	T	Laser welding.
13	Kwanwoo Kim (2011)	AISI 304 S.S.	FEA	Butt	Argon
14	Youngsoo Choi (2011)	SGACEN 0.7	FEA	Lap	Filler weld
15	Wen-feng Zhu (2010)	High-strength plate	FEA, Numerical	Edge	CO2 arc
16	Thakur.A.G (2010)	steel sheets	FEA, Numerical	Lap	Filler welds
17	Khan M.M.A.(2011)	AISI 416	FEA, Numerical	Lap	Laser welding
18	H.Naffakh(2010)	AISI 310, Inconel 657	Analytic	Butt	Argon Welding
19	K.Y. Benyounis (2008)	AISI 304.	Analytic	Butt	Laser welding
20	Dasharath Ram (2004)	Ti 6 Al4V	Analytic	Butt	EBW

Table No. 1.1: Summery of literature review

2.1. Findings of literature review:

Several analytical methods for calculations of stress distributions in welding joints are available in literature. However, implementation and use of analytic models are usually difficult, since they are complex non-linear functions of material properties and geometry. So it is better to go for numerical

a. Methods by utilizing user friendly software's, as these software permits calculation of stress distributions using each analytical solution individually, comparisons among different analytic solutions results and failure criteria analysis.
b. The need of joining different materials particularly associated with lightweight construction and offers an alternative method for welding or mechanical fasteners like bolts or rivets.
c. It is frequently required to join various materials, e.g. aluminium, magnesium and steel alloys. The methods such as welding and mechanical fastening have been used in the past to join dissimilar materials (dissimilar thickness or composition), work in this area is now moving towards less labour intensive methods, geared more toward automation.

2.2. Research Issues

a. Significant work has been reported on commonly use stainless steel material grade like AISI 304 and AISI 316.

Analysis of this stainless steel is done for chemical applications. [1, 8, 11, 13].

b. Little work reported for analysis of stainless steel under abrasive working environment.

c. Very little work is done using Surface Response Method for optimization of input process parameters of welding.

d. Very little work is reported on T joint of AISI 310.

e. It is necessary and important to understand the stress distribution and to predict strength for the welded joints under different types of external loadings.

f. Few studies have been conducted in the literature to simulate the welding process only because of inherent complexity of geometry, boundary conditions and nonlinearity of material properties.

Few studies have been conducted in the literature to simulate the welding process only because of inherent complexity of geometry, boundary conditions and nonlinearity of material properties.

3. PROBLEM DEFINATION AND METHODOLOGY

3.1. Problem Definition:

Effect of process input parameters on the strength of T type welded joint needs to be studied and optimized for stainless steel AISI 310 using Argon gas welding.

For present study, the tensile strength has been taken as performance measures for AISI 310. Hence the problem is to identify the most significant process parameters affecting tensile strength and obtain the optimal values of those process parameters.

3.2. Research Objectives:

a. To model and analyze T joint for Stainless Steel AISI 310 using FEA.

b. To optimize process parameters such as voltage, wire feed speed and welding Speed

c. For welding of stainless steel AISI 310 material using Argon gas metal arc welding.

d. To evaluate tensile and shear strength of welded joint.

e. Analysis of effect of input parameters on measurable response parameter using

f. ANOVA and surface response method.

g. Validation of FEA results with Experimentation.

3.3. Research Methodology:

a. Selection of process parameters such as Voltage, welding speed and wire feed

b. Speed and their values from literature review and initial experimentation.

c. Design of experiment considering three process parameters and their levels

d. Tensile and shear strength testing of welded joints using UTM (Universal Testing Machine).

e. FEA (Finite Element Analysis) analysis.

3.4. Selection of material :

From the experience of Small scale industry it was found that the T joint of blades of impeller, pump and turbine do not withstand to required product life. This is due to failure at T welded joint. Hence this study is focused towards the increasing the strength of T type welded joint made up of AISI 310. From the literatures, it is observed that only few works have been reported on the study of GMAW process parameters for welding of AISI 310.

AISI 310 is one of the most important engineering materials used in high temperature severe conditions. This material has extensive application at elevated temperature. AISI 310 has found suitable application in oil and gas industries because of their high resistance to corrosion, hot oxidation, fatigue and creep rupture. Chromium content in AISI 310 forms adherent

oxide layer that can protect material from oxygen attach where as nickel improves high temperature strength and resistance to carburizing atmospheres. T joint is used in blades of pump, blowers and turbine, turbomachinaries, utensils, construction joints and automobiles.

Physical properties of AISI 310:

Material	Young's Modulus (E) in MPa	Poisson's Ratio (ν)	Density (ρ) in Kg/m3	Specific heat J/Kg. K	Thermal conductivity W/m.K
AISI 310	200 x 10^3	0.3	7900	500	14.2

Table No. 3.1: Physical properties of AISI 310

Chemical properties of AISI 310:

Material	C %	Mn %	Si %	P %	S %	Cr %	Ni %
AISI 310	0.25	2	1.5	0.045	0.030	23-26	18.0 - 22.0

Table No. 3.2: Chemical properties of AISI 310

Application of AISI 310:

a. Cryogenic Components.
b. Food Processing.
c. Furnaces: - burners, doors, fans, piping and recuperators.
d. Fluidized Bed Furnaces: - coal combustors, grids, piping and wind boxes.
e. Ore Processing/Steel Plants: - smelter and steel melting equipment, continuous casting equipment.
f. Petroleum Refining: - catalytic recovery systems, flares, recuperators, tube hangers.
g. Power Generation: - coal gasifier internals, pulverized coal burners, tube hangers.

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h. Sintering/Cement Plants: - burners, burner shields, feeding and discharging systems, wind boxes.
i. Thermal Processing: - annealing covers and boxes, burner grids, doors, fans, muffles and retorts, recuperators, walking beams.

3.5. Selection of welding process :

3.5.1. Welding definition

A fabrication process that joins the material usually metals by melting the part of metal to be joined and adding some additional molten joining material

3.5.2. Types of welding processes:

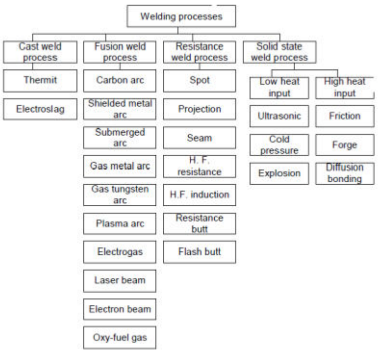


Fig. No. 3.1: Welding processes.

3.5.3 Gas Metal Arc Welding (GMAW):

Gas metal arc welding is, "an arc welding process which produces coalescence of metal by heating them with an arc between continuously fed filler metal electrode and work." The process uses shielding from externally supplied gas to protect the molten metal pool.

Shielding gases used in GMAW are inert gases and reactive gases. Argon and helium are the two inert gases used for the protecting the molten metal pool. Oxygen, hydrogen, nitrogen and carbon dioxide are the reactive gases.

In this dissertation GMAW is preferred over other welding processes because of the following advantages and benefits of GMAW.

3.5.4 Advantage of GMAW

a. The ability to join wide range of material type and thicknesses.

b. Simple equipment component are readily available and affordable.

c. GMAW has higher electrode efficiencies, generally between 93% and 98 % when compared to other welding processes.

d. GMAW is easily adapted to high speed robotic, hard automation and semiautomatic welding operation.

e. Higher welder efficiencies and operator factor, when compared to other open arc welding processes.

f. All-position welding capability.

g. Excellent weld bead appearance.

h. Lower heat input when compared to other welding processes.

i. A minimum of weld spatter and slag makes weld clean up fast and easy.

j. Less welding fumes as compared to shielded metal arc welding and Fluxed- cored Arc welding.

3.5.5 Benefits of GMAW

a. Generally, lower cost per length of weld metal deposited when compared to other open arc welding processes.

b. Lower cost electrode.

c. Less distortion.

d. Reduced welding fume generation.

e. Minimal post-weld cleanup.

3.5.6 Selection of shielding gas:

Selection of shielding gas for particular application is critical to the quality of the finished weld. Argon and helium are the two inert gases used for the protecting the molten metal pool. Neither Argon nor helium will react chemically with the molten weld pool. However, in order to become conductive gas, the gas must be ionized. The thermal conductivity, or the ability of the gas to transfer thermal energy, is the most important consideration for selecting a shielding gas. High thermal conductivity levels result in more conduction of the thermal energy into the work piece. The thermal conductivity also affects the shape of the arc and the temperature distribution within the region.

In this dissertation argon is selected over the helium as a shielding gas because of the following properties of the argon,

a. Argon has less ionization energy than helium so it is easier to ionize argon which facilitates better arc starting.

b. The high thermal conductivity of helium will provide a broader penetration pattern and will reduce the depth of penetration. Gas mixtures with high percentages of argon will result in a penetration profile with a finger-like projection into the base material, and this is due to the lower thermal conductivity of argon.

c. 100% argon shielding used for the material with base of Nickel, copper, aluminum, titanium, and magnesium.

d. It increases the molten droplet transfer rate.

3.5.7 Selection of welding process parameter

Welding involve wide range of scientific variable such as time, temperature, power input, electrode, welding speed etc. Welding factors are the most important factors affecting the quality, productivity and cost of welding joint. Welding process parameter include voltage, current, welding speed, wire feed speed, gas flow rate, electrode diameter, electrode advance angle.

In this Research voltage , wire feed speed and welding speed are taken as varying welding process parameter by keeping all other process parameter constant. To determine the welding parameters, the national and international welding standards and also welding experiences in application are taken into consideration for gas metal arc welding method.

4. DESIGN OF EXPERIMENT

4.1 Introduction

Design of experiments was developed in the 1920s by Sir Ronald Fisher at the Rothamsted Agriculture field Research Station in London, England. His initial experiments were concerned with determining the effect of various fertilizers on different plots of land. The final condition of the crop was not only dependent on the fertilizer but also on the number of other factors (such as underlying soil condition, moisture content of the soil, etc.) of each of the respective plots. Fishers used DOE which could differentiate the effect of fertilizer and the effect of other factors. Since that time the DOE has been widely accepted in agricultural as well as Engineering Science. Design of experiments has become an important methodology that maximizes the knowledge gained from experimental data by using a smart positioning of points in the space. This methodology provides a strong tool to design and analyze experiments; it eliminates redundant observations and reduces the time and resources to make experiments.

4.2 Taguchi's Robust Design Method:

Since 1960, Taguchi methods have been used for improving the quality of Japanese product with great success. During the 1980‟s, many companies finally realized that the old methods for ensuring quality were not competitive with the Japanese methods. The old methods for quality assurance relied heavily upon inspecting products as they rolled off the production line and rejecting those products that did not fall within a certain acceptance range. However Taguchi was quick to point out that no amount of inspection can improve a product; quality must be designed into a product from the start. Robust design is an "engineering methodology for improving productivity during research and development so that high-quality products can be produced quickly and low cost" (Phadake M. S. 2009). The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult or too expensive to control). This method is an off-line quality control method that is instituted at both the product and process design stage to improve product manufacturability and reliability by making products intensive to environmental conditions and components variations. The end result is a robust design, a design that has minimum sensitivity variations in uncontrollable factors.

Dr. Genichi Taguchi bases his method on conventional statistical tools together with some guidelines for lying out design experiments and analyzing the results of their experiments. Taguchi approach to quality control applies to the entire process of developing and manufacturing a product, from the initial concept, through design and engineering to manufacturing and production.

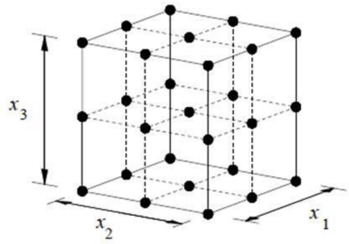
4.3 Orthogonal array:

A matrix experiment consists of a set of experiments where the settings of several product or process parameters to be studied are changed from one experiment to another. Matrix experiments are also called designed experiments, parameters are also called factors and parameters settings are called levels. Conducting matrix experiments using orthogonal arrays is an important technique in robust design. It gives more reliable estimates of factor effect with fewer experiments as compared to the traditional method, such as one factor at a time experiments. More factors can be studied to more robust and less expensive products. The columns of an orthogonal array are pair wise orthogonal i.e. for every pair of columns, all combinations of factor level occurs an equal number of times. Orthogonally means that factors can be evaluated in depending of one another; the effect of one factor does not bother the estimation of the effect of another factor. The columns of the orthogonal array represent factor to be studied and the rows represent individual experiments (Phadake M.S., 2009). Taguchi has tabulated 18 basic orthogonal arrays and are called as standard orthogonal arrays. An array's name indicates the number of rows and columns it has, and also the number of level in each of the column. Thus L18 (2 3) has 18 rows, one 2-level and seven 3-level columns. The number of rows of an orthogonal array represents the number of experiments. The number of columns of an array represents the maximum number of factor that can be studied using this array. In order to use a standard orthogonal array directly, number of levels of factor should be matched with the number of levels of column. Smallest possible array should be used to reduce the cost of experiments. The first step in selecting an orthogonal array to fit a specific study is to count the total degree of freedom that tells the minimum number of experiments that just be performed to study all the chosen control factors. A degree of freedom in a statically sense is associated with each piece of information that is estimated from the data. The mean is estimated from all the data and requires one degree of freedom for that purpose. The number of degrees of freedom associated with a factor is equal to one less than the number of levels for that factor. Selected orthogonal array for conducting experiments should contain number of rows. Number of experiments equal to or more than total degree of freedom for that case study (Ross P. J., 1996). Thus smallest possible orthogonal array that meets the requirement should be used as it is expensive to conduct experiments.

Once the appropriate orthogonal array is selected, the factors can be assigned to various columns of the array, after assigning the factors, parametric combination for each experiment is obtained. Accordingly tests are conducted to get result in the form of response outputs.

4.3.1 Full factorial design:

A full-factorial experiment is better strategy as it is orthogonal. There is equal number of test data points under each factor. Because of this balanced arrangement other factors does influence the estimate of a particular factor. In full factorial there is N^f (f is number of factors each at N level) possible combinations that must be tested. So full factorial experiment is acceptable only when there is limited number of factors, as it is expensive and more time is required to conduct more number of experiments. A factorial experiment is an experimental strategy in which design variables are varied together, instead of one at a time. The lower and upper bounds of each of N design variables in the optimization problem needs to be defined. The allowable range is then discretized at different levels. If each of the variables is defined at only the lower and upper bounds (two levels), the experimental design is called 2^N full factorial. Similarly, if the midpoints are included, the design is called 3^N full factorial. And is shown in the figure 4.1



An efficient way to study the effect of several control factors simultaneously is to plan matrix experiments using Taguchi's orthogonal arrays. Orthogonal array offers more benefits

a. The conclusion arrived at from such experiments are valid over the entire experimental region spanned by control factors and their settings.

b. There is a large saving in experimental effort.

c. The data analysis is very easy. In the present study the Taguchi's method have been used to plan the experiments.

The first step in implementing the Taguchi method is parameter design. Parameters are various inputs suspected or known to have an effect on the quality characteristics, and might include such things as rate of flow, temperature, humidity or reaction time.

Parameter design is an investigation to determine which variables or parameters have an effect on the quality characteristic .Designing high quality and low variability into the product will not only be much cheaper than extensive or exhaustive inspection, but also will allow a product to go from blueprint to usable product in much less time. Variables suspected to have some effect on the quality characteristic of interest are known as factors. At this point any expert knowledge of the subject matter should be applied in the selection of variables to include as factors. Those variables suspected to have the largest effects on the quality characteristic are generally considered first, but it is very possible to (unknowingly) omit variables that should have been considered and also to include others that have no effect on the quality characteristic. Once chosen these variables are then classified into one of two categories; control variables or noise variables. Control variables represent those parameters or factors which can be controlled by the designer or manufacturer. In contrast, noise variables are those parameters which may have an effect on the quality characteristic but generally cannot be controlled by the designer. Variables that are very expensive or very difficult to control may also be considered noise variables. In order to screen these variables for their effect on the quality characteristic, a classical Taguchi designed experiment takes place. Various settings are selected for each of the control variables and various settings are temporarily fixed for each of the noise variables.

4.4. Selection of level of input process parameter:

In this study three process parameters have been chosen for analysis. They are voltage welding speed, and wire feed speed. Literature review, several initial trial runs and past experience of the expertise from industries is taken into consideration to determine the range of process parameters.

5. ANOVA and RSM

5.1 Data analysis:

The final phase of the design of experiment is to analyze and interpret the experimental results to improve the performance characteristics of the product or process relative to customer needs and expectations. After all tests are conducted, decisions must be made concerning which parameters affect the performance of a product or process. The first step in data analysis is to summarize the data for each experiment. For each experiment appropriate S/N ratio for response outputs are calculated. (Ross P.J., 1996).

5.2 Analysis Of Variance (ANOVA):

This method was developed by Professor R.A.fisher. ANOVA is an extremely useful technique which is used when multiple sample cases are involved. The basic principle of ANOVA is to test the means of the population by examining the amount of variation within each of this sample relative to the amount of relation between the samples. In terms of variation within the given population, it is assumed that the value of (yij) differ from the mean of this population only because of random effects that is there are influences on (yij) which are unexplainable, where as in examining difference between the mean of the jth population and the grand mean is attributable to what is called air treatment effect. Thus it has to make to estimate of population variance viz. one based on between sample variance and the other based on within sample variance. Then these two instruments of population variance are compared with F-test.

$$F = \frac{\text{Estimate of population variance based between sample variance}}{\text{Estimate of population variance based on within sample variance}}$$

This value of F ratio be compared to the F-limit for given degree of freedom. If the F value worked out is equal or exceed the F- limit table value, it may conclude that there are significant differences between the sample means. (Kothari C.K., 2004).

5.2.1 Selecting optimum factor levels:

A primary goal in conducting a matrix experiments is to optimize the product or process design, to determine the best or the optimum level for each factor. The optimum level for a factor is the level that gives the highest value of S/N ratio in the experimental region. The estimated main effects can be used for this purpose provided the variation of S/N ratio as a function of the factor level follows the additive model (Phadake M.S., 2009)

5.2.2 Signal to noise ratio:

The Taguchi method includes the noise factors in the experiment for the purpose of identifying control factors settings which are robust against noise, i.e. those settings of the design factors which produce the smallest variation in the response across the different levels of the noise factors. Some combinations of control factor settings may yield output that is affected by the noise factors, thus causing the response to vary around its mean, while for other combinations; the output is insensitive to the changes in the noise factors (Phadake M.S., 2009). Similarly, the quality characteristic might exhibits more variability at, say, the low setting of a certain control factor than it does at the high setting. For other control factor, the variation in the quality characteristic might be nearly constant across the levels of those control factors, while the average quality characteristic might or might not change across the levels of these control factors. For any control factor, there are four possible situations (effect or no effect on the mean, coupled with effect or no effect on the variation). Some factors may arise that impact the mean but not the variations such „adjustment" factors may be used to move a process onto or towards its target value, without affecting the variation around the target. In a two-step adjustment process, the variation is minimized by the appropriate setting of the factors that affect the variation, and then the output is centered at the target value by the appropriate settings of the factors that only influence the mean. Factors which appear to have little or no impact on either the mean or the variation are typically set to the level representing the lowest cost. In order to achieve its goals, the Taguchi method analyses not the measured response but rather some transformation of that response, depending on the situation. As Taguchi method aims to minimize the expected loss, $E(y - m)^2$, but it does not base the analysis on this quantity directly. A signal to noise ratio is calculated, the choice of the particular signal to noise ratio depends on the desired outcome of the response as below. (Roy R.K., 1990).

i) Smaller the better type problem:

In this case the quality characteristic is continuous and nonnegative, i.e. it can take any value from 0 to infinity. Its most desired value is zero. The surface defect count is an example of this type of problem.

$$S/N = -10 \log_{10}(MSD)$$

MSD = Mean squared deviation from the target value of the quality characteristic

$$= \frac{(y_1^2+y_2^2+y_3^2+\dots+y_n^2)}{n}$$

Where, yi = result of observation

n = number of repetitions

ii) Nominal the best type of problem:

In this case the quality characteristic is continuous and nonnegative i.e. it can take any value from 0 to ∞.

Its target value is nonzero and finite.

S/N = - 10 Log_{10}(MSD)

MSD = Mean squared deviation from the target value of the quality characteristic.

$$= \frac{[(y_1-m)^2+(y_2-m)^2+(y_3-m)^2+\dots+(y_n-m)^2]}{n}$$

n = number of repetitions

m = target value of result

Where, y_i =result of observation

iii) Larger the best type of problem:

In this case the quality characteristic is continuous and nonnegative, and we would like it to be as large as possible.

S/N = - 10 Log_{10}(MSD)

MSD =Mean squared deviation from the target value of the quality characteristic

$$= \frac{(\frac{1}{y_1^2}+\frac{1}{y_2^2}+\frac{1}{y_3^2}+\dots+\frac{1}{y_n^2})}{n}$$

Where, y_i = result of observation

n = number of repetitions

For all three situations, the analysis falls under Taguchi`s idea of signal to noise ratio, although only in the target is best case both signal and noise are considered. The greater this value, the smaller the product variance around the target value.

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