# Effects on hardness and Penetration on changing process parameters in TIG welding using optimization techniques

**Nehar Ansari [1], Dr. Lokesh singh[2]**

*Department of mechanical engineering*
*G D Rungta college of engineering and technology, Kohka Bhilai,India 490020*

***Abstract –*** *An optimization problem has been created in search of an ideal parametric combination to yield good bead geometry on plate element. Taguchi $L_9$ orthogonal array design and the concept of signal-to-noise ratio have been utilized to derive objective functions to be enhanced within the experimental zone. In this trial, we utilize three kinds of oxide fluxes $TiO_2$, $SiO_2$, and $Al_2O_3$ as examining the impact of activated tungsten inert gas of mild steel. We applied for 6 mm thick plates through a slim layer of flux to make bead-on-plate welded joint. In this analysis, $SiO_2$ flux easier joint penetration, but $Al_2O_3$ flux led to better weld depth and bead width compared with conventional TIG process. So we can say that Activated tungsten inert gas welding can expand the joint penetration and weld depth-to-width ratio. The objective functions have been chosen as the parameters of bead geometry viz. hardness, reinforcement, penetration and depth-to-width ratio. The factors on overall output feature of the component have been assessed quantitatively by analysis of variance method. The optimal result has been verified through experiment which shows to progress as product quality in a manufacturing industry and Light optical microscope analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality.*

***Keywords Orthogonal array, signal-to noise ratio, Hardness, Reinforcement, Penetration, depth-to-width ratio, Light optical microscope***.

## I-INTRODUCTION

**W**elding is a manufacturing process of creating a permanent joint obtained by the fusion of the surface of the parts to be joined together, with or without the application of filler material and pressure. The materials to be joined may be similar or dissimilar to each other. The heat required for the fusion of the material may be obtained by an electric arc and burning of gas. The latter method is more extensively used because of greater welding speed. Welding is extensively used in fabrication as an alternative method for casting or forging and as a replacement for bolted and riveted joints. It is also used as a repair medium e.g. to reunite a metal at a crack or to build up a small part that has broken off such as a gear tooth or to repair a worn surface such as a bearing surface.

**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 vapour [4]. 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 20,000 $^0$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 is shown in figure.1.

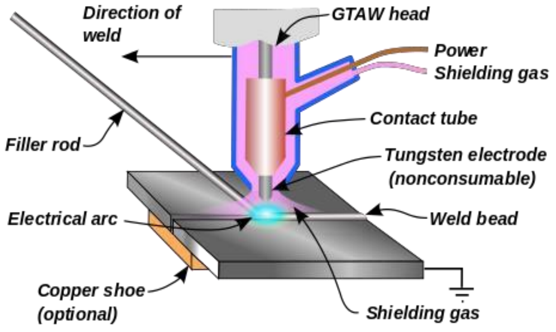



Fig 1: Principle of TIG welding.

**PROBLEM IDENTIFICATION**

The tungsten inert gas welding is most commonly uses to joining of metals in power generation, electronic, nuclear reactors and petrochemical industries. The welding of the material face variety of problem such as cracking, reduction of strength, porosity, surface quality and stress due to thermal, mechanical and chemical properties of the materials. For reduce of this problem the optimization of process parameter in tungsten inert gas welding need to be study. In tungsten inert gas welding process, there is several important parameters need to concern.These parameters are welding speed, arc travel speed, gas flow rate, arc voltage, torch angle and nozzle distance. Some investigators had studied the effect of various parameters on the mechanical properties of the base metal and go through the micro-structural changes and their effect. Some investigators have optimized the gas tungsten arc welding process by using optimization techniques like Taguchi Design of Experiments and Analysis of Variance. Some of the research work is carried out in the direction of the metallurgical aspects and micro-structural properties of the base metal after welding in the base metal, weld metal and heat affected zone. Research work has also been carried out by varying the shielding gas flow rate during gas tungsten arc welding process and studying its effect on the various mechanical properties and microstructure of base metal. It can be concluded from literature review that the main process parameter which affect the properties of weld bead geometry is, welding current, gas flow rate, and arc travel speed chosen composition of base metal and filler metal.

After literature survey it is concluded that output of a welding process can be maximize/minimize and maintained at desired level with optimizing the different process parameter by finding the most affecting factor/parameters at different level with the Taguchi method

**1.** To reducing the total number of experiments.
**2.** To assessing the importance of one or more factor by comparing the responsible variable means at the different factor level.
**3.** ANOVA method-by assessing the importance of one or more factor by comparing the responsible variable means at the different factor level.

**PROCESS PARAMETERS OF TIG WELDING**

**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.

A significant disadvantage is the decreased weld quality associated with a varying arc length and difficulty of striking an arc with helium gas. Argon-helium mixtures are also frequently used in GTAW, since they can increase control of the heat input while maintaining the benefits of using argon. Normally, the mixtures are made with helium (about 75% or higher) and a balance of argon gas. These mixtures increase the speed and quality of the AC welding of aluminium and also make it easier to strike arc. Another shielding gas mixture (argon-hydrogen) is used in the mechanized welding of light gauge stainless steel, but as hydrogen can cause porosity, so its uses are limited. Similarly, nitrogen can sometimes be added to argon to help stabilize the austenite in austenitic stainless steels and increase penetration in welding copper. Due to problems of porosity in ferrite steels and limited benefits, however, it is not a popular shielding gas additive. Present worked used pure argon shielding.

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.

5. **Electrode:**

The electrode used in GTAW is made of tungsten or tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,400 °C. As a result, the electrode is not consumed during welding although some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish. Clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them effective for heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 millimetres, and their length can vary from 75 to 610 millimetres. A number of tungsten alloys have been standardized by the International Organization for Standardization and the American Welding Society in code ISO 6848 and AWS A5.12, respectively, for use in GTAW electrodes, and are summarized below. Pure tungsten electrodes (classified as WP or EWP for general purpose and have low cost.

These have poor heat resistance and electron emission. They find limited use in AC welding of magnesium and aluminium. Thorium oxide alloy electrodes can withstand somewhat higher temperatures while providing many of the benefits of other alloys and were designed for DC applications. However, it is somewhat radioactive in nature. Inhalation of the thorium grinding dust during preparation of the electrode is hazardous to health. As a replacement to thoriated electrodes, electrodes with larger concentrations of lanthanum oxide may be used. Larger additions than 0.6% help with electron emission but do not have additional improving effect on arc starting. Higher percentage of thorium makes tungsten more resistant to contamination. Electrodes containing zirconium oxide (zirconium) increase electrode life and also current capacity while improving arc stability and starting. Zirconium-tungsten electrodes melt easier than thorium-tungsten electrodes. In addition, electrode manufacturers may create alternative tungsten alloys with specified metal additions in appropriate quantity and these are designated with the classification EWG under the AWS system. Filler metals are also used in nearly all applications of GTAW (the major exception being the welding of thin materials). Filler metals are in a variety of materials and are available with different diameters. In most cases, the filler metal (in the form of a rod) is added to the weld pool manually, but some applications call for an automatically fed filler metal, which often is stored on spools.

Table 1: tungsten electrode specification for GTAW

| Sr. No. | AWS Classification | Material | Thorium | Zirconium | Tip Colour |
|---|---|---|---|---|---|
| 1 | EWP | Pure tungsten | ------- | -------- | Green |
| 2 | EWTh-1 | Tungsten + 1% Thorium | 0.8-1.2 | -------- | Yellow |
| 3 | EWTh-2 | Tungsten + 2% Thorium | 1.7-2.2 | -------- | Red |
| 4 | EWZr | Tungsten + Zirconium | -------- | 0.15-0.40 | Brown |

**Welding torch**

GTAW welding torches are designed for both automatic and manual operation and are equipped with cooling systems using air or water. The automatic and manual torches are similar in construction, but automatic torch normally comes with a mounting rack and the manual torch has a handle. Head angle i.e. the angle between the centerline of the handle and the centerline of the tungsten electrode can be varied on some manual torches according to the preference of the operator. Water cooling is required for high-current welding (up to 600 Amp.), while air cooling systems are most often used for low-current operations (up to about 200Amp.). The torches are connected with cables to the power supply, with hoses to the shielding gas source and where used, with pipe to the water supply. The internal metal parts of a torch are made of copper or brass (of hard alloys) in order to transmit current and heat effectively. The tungsten electrode must be held strongly in the centre of the torch with an appropriately sized collect and ports around the electrode provide a regular flow of shielding gas. The diameter of the tungsten electrode decides the collect size as it holds the electrode. The body of the torch is made of heat-resistant, insulating plastics covering the metal components, providing insulation from heat and electricity to protect the operator. The size of the welding torch nozzle depends on the extent of shielded area desired. The size of the gas nozzle will depend upon the joint configure ration, the diameter of the electrode and the availability of access to the joint by the welder. The inside diameter of the nozzle is preferably at least three times the diameter of the electrode, but there are no hard and fast rules. The welder will judge the effectiveness of the shielding and increase the nozzle size to increase the area protected by the external shielding gas according to needed. The nozzle must be heat resistant and thus is normally made of alumina or a ceramic material, but fused quartz (a glass-like substance) offers greater visibility

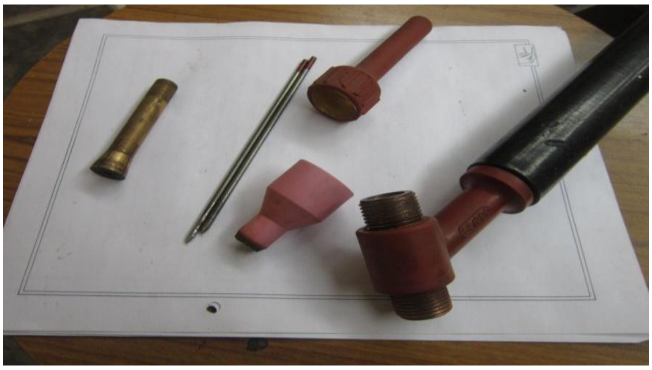


*Fig 2: GTAW Torch with collect, electrode, ceramic cup handle.*

**Effect of Process Parameters on Welding**

**Shekhar Srivastava, et al (2017)** studied on weld quality which depends on mechanical properties of weld metal and heat affected zone that direct relation to the type of welding and its process parameters i.e. welding speed, welding current, shielding gas flow rate, voltage, arc travel speed, type of shielding gas etc. Bead geometry, heat affected zone, bead width, bead height and Penetration are greatly influence by process parameter. In this paper, effect of the various process parameters has studies on welding of IS:2062 mild steel plate using gas metal arc welding process with a copper coated mild steel wire of 0.8 mm diameter.

**Pravin Kumar Singh, et al (2017)** studied on mechanical properties of 6 mm thick butt welded mild steel plates. The important process parameters of vibratory welding technique namely welding, welding speed and frequency of the vibrations induced in molten weld pool were optimized using Taguchi's analysis and Response surface methodology. The effect of process parameters on tensile strength and hardness were obtained through two separate regression equations.

**Nabendu Ghosh, et al (2017)** studied on welding process parameters which play the role to determining the quality of the welded joint in metal inert gas welding operation. In this paper we analyse the effects of welding parameters i.e. welding current, gas flow rate and nozzle to plate distance on ultimate tensile strength and percentage elongation in metal inert gas welding of AISI409 ferrite stainless steel materials.

**Pradip Kumar Pal, et al (2017)** studied on visual inspection and X-ray radiographic test to detect surface of weld specimens made of AISI 316L austenitic stainless steels. In this paper, effect of current, gas flow rate and nozzle to plate distance on quality of weld in metal inert gas arc welding of AISI 316L austenitic stainless steel of the butt welded joints made by using several levels of current, gas flow rate and nozzle to plate distance.

**T. Kannan, et al (2015)** studied on the effect of flux-cored arc welding process parameters on the quality of super duplex stainless steel claddings using Taguchi L9 design of experiments. In this paper, to establishing the optimum combination of process parameters is requires to ensure better bead geometry and properties.

**P. Sathiya, et al (2013)** studied on welding of super austenitic stainless steel sheet using gas metal arc welding process with AISI 904 L super austenitic stainless steel with solid wire of 1.2 mm diameter. The input parameters (gas flow rate, voltage, travel speed and wire feed rate) are selected based on the filler wire thickness and base material thickness and the corresponding output variables such as bead width (BW), Bead height (BH) and depth of penetration (DP) are measured using optical microscopy.

**Challenges**

In today's manufacturing world, quality is of vital importance. Quality can be defined as the degree of customer's satisfaction as provided by the procured product. The product quality depends on the desired requirements gained in the product that suits its functional requirements in various areas of application [9]. In the field of welding, weld quality mainly depends on mechanical properties of the weld metal and HAZ, which in turn is influenced by metallurgical characteristics and chemical compositions of the weld. It is very cumbersome process for designers and engineers to develop steels with higher yield strengths combined with good toughness at low temperatures. Increase in strength is usually linked together with a decrease in toughness unless steps are taken to prevent it such as the refinement of the microstructure [14]. Maintaining of quality in products is a challenge in today's manufacturing industries. One of such means is by controlling the process parameters of the manufacturing process. As discussed earlier quality of a weld joint is directly influenced by the welding parameters during the welding process. Often, a common problem that has been faced by the manufacturer is the control of the process parameters to obtain a good welded joint.

**Scope**

The literature survey presented in next chapter shows an Ample scope for the study of elemental effect on the microstructure and mechanical properties of weld metal in TIG process. In order to increase the mechanical properties of welds for low-carbon steels, the selection of an appropriate process parameter plays a very important role to obtain a desirable microstructure, which has been shown to improve the properties in this type of welds. It is well known that high efficiency and high quality is the developing target of welding technology. Several process control parameters influence directly or indirectly on various aspects of TIG. These control parameters includes Welding Current, Welding Speed and Gas Flow Rate.

## MATERIAL AND METHODOLOGY

**1.Materials:**

Mild steel is used for the present investigation. The chemical compositions of the base material (mild steel) as given in Table 2.

*Table 2: Chemical composition of Mild Steel*

| Component | C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Al % |
|---|---|---|---|---|---|---|---|---|---|
| Weight % | 0.18 | 1.02 | 0.02 | 0.005 | 0.14 | 0.0108 | 0.0038 | 0.014 | 0.052 |

.

For mild steel parent material, a copper coated mild steel electrode wire ER70S3 is used which supplied by **Raghuvir ferro Alloy Pvt. Ltd Raipur**. Wire diameter is 2 mm and its chemical composition is given in Table 3.2. A fused flux [$TiO_2$, $SiO_2$ and $Al_2O_3$] of grain size 0.2 to 1.6 mm with basicity index 1.6 is used to perform the welding.

*Table 3: Chemical composition of MS material wire consumable.*

| Element | C | Mn | Si | P | Cr | S |
|---|---|---|---|---|---|---|
| MS ER70S3 | 0.08 | 1.05 | 0.65 | 0.025 | 0.023 | 0.035 |

The flux used for welding is $TiO_2$ and Chemical Composition of flux is

**Chemical Composition of $TiO_2$ Flux**

Purity as $TiO_2$: 99.9%
$Fe_2O_3$: 0.01%
CaO: 0.0033%
$Al_2O_3$: 0.013%

**Physical Properties $TiO_2$ Flux**

Oil absorption value: 15-20 ml/ 100 gm
Sp. gravity: 2.65
Refractive index: 1.55
Loss on ignition: 0.3%
PH of 10% aqueous solution:

**Welding Parameters and Procedure**

The goal of the present work is to see the effect of titanium dioxide ($TiO_2$), silicon dioxide ($SiO_2$) and aluminium dioxide ($Al_2O_3$) powder additions in the flux on the microstructure and bead geometry i.e. bead reinforcement, depth of penetration and depth-to-width ratio in Tungsten inert Gas welded metals. For that purpose, the welding process parameters are kept constant. But the selection of process parameters is a major problem.

*Table 4: welding process parameter.*

| Parameters | Units | Notation | |
|---|---|---|---|
| **Welding Current** | Amp. | I | 180 |
| **Welding Speed** | mm/sec. | S | 3 |
| **Gas Flow Rate** | Lit./min. | $F_r$ | 10 |

The welding parameters are chosen on the basis of the trial-and-error method by varying one factor at a time. Previous literature survey helps to identify many factors which are believed to influence the response parameters. Based on this pilot study results, various welding parameters viz. current, gas flow rate and speed are identified as control factors which are given in Table 3.3. Tungsten inert gas welding is carried out in mild steel in the flat position with single pass welding. The base metals cut into (80×60×6) $mm^3$ rectangular strips then cleaned with a steel wire brush and 80-grade abrasive paper before the welding. Titanium dioxide, silica dioxide, and alumina dioxide powder have mixed in the same ratio with Acetone for making the paste on the various weld metals composition. Beyond this maximum limit powder could not be added because, after that limit, welding is not good (visual inspection) and detachability of slag also poor. Welding has conducted in a tungsten inert gas welding machine model: **NRS welding machine available in Raipur**. After completion of all the welding, the welded plates are cooled in air. Then, slag removed using chipping hammer. Finally, the weld joints cleaned by brush.

## METHODOLOGY

For the present work, experimental has done in two phase. In the first phase, welding of mild steel plate (6 mm thickness) done at different types of oxide flux i.e. $SiO_2$, $TiO_2$, and $Al_2O_3$ on weld bead with constant welding process parameters (welding current, welding speed and gas flow rate).

In the second phase, the welding of mild Steel plate done with best oxide flux $TiO_2$ and varying welding process parameter i.e. welding current, welding speed and gas flow rate. Commercial mild steel plate of thickness 6mm has selected as workpiece material for the present experiment. A mild steel plate is cut with a dimension of 80×60 (in mm) with the help of hacksaw machine and grinding done at the edge to the smooth weld surface. After that surfaces are polished with emery paper to remove any kind of external material. After sample preparation, mild steel plates are fixed in the working table with flexible clamp both sides and welding done so that weld bead geometry can be formed. Tungsten inert gas welding with direct current has used in experiments as it concentrates the heat in the welding area. Zirconiated tungsten electrodes of diameter 2.4 mm has taken as an electrode for this experiment. The end of the electrode has prepared by reducing the tip diameter to 2/3 of the original diameter by grinding and striking an arc on a scrap material piece.

**The welding setup consists mainly of following parts:-**

**A) TIG welding torch-** Torch is fixed with the movable tractor unit. A tungsten electrode is fixed in the torch and Ar gas flows through this.

**B) TIG welding machine–** This is the main part of TIG welding setup by which controlled the amount of current and voltage is supplied during welding. A Rectifier with current range 10-180 A and voltage up to 230 V, depending on the current setting has been used.

**C) Gas cylinder-** For TIG welding Ar gas is supplied to the welding torch with a particular flow rate so that an inert atmosphere formed and stable arc created for welding. Gas flow is control by regulator and valve.

**D) Work holding table-** a surface plate (made of grey cast iron) is used for holding the work piece so that during welding gap between the tungsten electrode and work piece is maintained. Proper clamping has been used to hold the work piece.

**Sample Preparation:**

After conducting all the welding experiment different testing performed to study the microstructures and bead geometry i.e. reinforcement, penetration and depth-to-width ratio of weld joints. Test sample dimension of 50 mm long and 6 mm wide cut transverse to the welding direction by Chop saw cutter machine. Figure 3.3 shows the schematic diagram of the welding plate with the different testing plates.


*Fig 3: MS Plate cutting setup.*

After cutting, test sample polished according to standard procedure ASTM for the metallographic and bead geometry study. Initially, the sample are polished using different grades of emery papers up to 1500 in an automatic double polishing machine. Finally, the samples are cleaned with acetone. For the measurement of inclusion size the unetched sample have been used. Etching of mild steel sample performed by 2% Nital solution (2% volume $HNO_3$ and 98 % volume Ethyl alcohol) for 10-15 seconds.

**Microstructure Tests:**

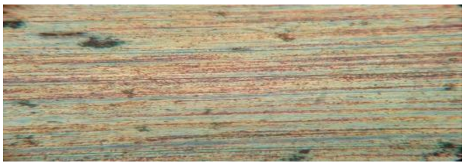
The microstructure study is necessary to see the bead geometry parameters viz. hardness reinforcement, penetration and depth-to-width ratio. It performed in a microscope as shown in figure 3.3 (b). Microphotographs are necessary for tracing the variation in weld bead shape due to the $TiO_2$, $Al_2O_3$ and $SiO_2$ addition as an active flux. The welding process parameters are the same in the first phase of welding, even though there is a chance of variation in bead geometry parameters due to the presence of oxides. Literature highlighted that oxides have a significant effect on the weld penetration. In the second phase of welding bead geometry parameters will definitely change due to the variation of heat inputs.

**LOM**

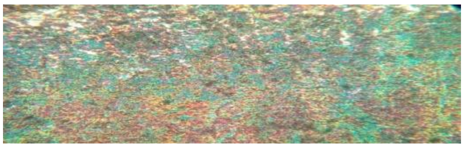
Light optical microscopy study is one of the most commonly used techniques for material characterization. Microscopes are required for the examination of the microstructure of the metals. In principle, optical microscopes may be used to look through specimens ('in transmission') as well as at them ('in reflection'). An optical microscope as Shown in figure.3.4, the light microscope is used to study the microstructure.

*Fig 4: light optical microscope.*

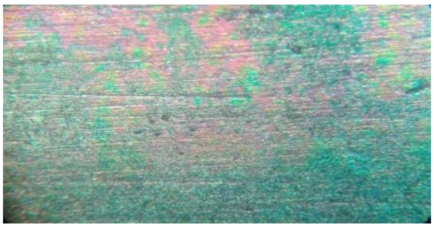
The atoms at the grain boundaries are chemically more active and consequently dissolve more readily than those within the grains forming small grooves. These grooves become visual when viewed under a microscope because they reflect light at an angle different from that of the grains themselves. When the microstructure of a two-phase alloy is to be examined, an etchant is chosen that produces a different texture for each phase so that the different phases may be distinguished from each other. Figure.5 shows the light optical micrograph of the welded mild steels corresponding to fluxes $SiO_2$, $TiO_2$, $Al_2O_3$ and without flux. The microstructure of the weld metal for each flux consisted mainly of equated pearlite, acicular ferrite, polygonal ferrite, grain boundary ferrite etc



SiO2 flux



TiO2 Flux



Al2O3 flux

Without flux

*Fig 5: Microstructure of different metals corresponding to different flux.*

**Parametric Optimization**

The parametric optimization for better bead geometry of the joint has been carried out by adapting the Taguchi method. Taguchi Method is a robust method for single objective optimization. In the present investigation four response parameters i.e. Hardness, reinforcement, depth of penetration and depth-to-width ratio of the welded joints are considered, the multi-objective optimization problem has been converted into a single objective optimization problem by using utility theory

**Taguchi Design of Experiment**

Taguchi's method for engineering system design and process control has been used successfully by many industries in Japan and elsewhere. It uses experimental designs primarily as a tool to make products more robust. That is, it considers experimental design as a means for reducing the sources of variation on process. Taguchi's philosophy is an efficient tool for the design of high-quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides a much-reduced variance for the experiment with an optimum setting of process control parameters. Thus the integration of the design of experiments with parametric optimization of the process to obtain desired results is achieved in the Taguchi method. The orthogonal array provides a set of well-balanced experiments and Taguchi's signal-to-noise ratios (S/N), which is logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, the Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product to be optimized [2]. The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio. Design of experiment is used in many industrial sectors, for instance, in the development and optimization of manufacturing processes. Other types of application where DOE is useful is robustness testing and mixture design. For the variation of the Process parameter is given in Table 4.

*Table.4: Process parameters and their levels of Taguchi $L_9$ DOE*

| Parameters | Notation | Unit | Level of Factors | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| **Welding Current** | I | Amp. | 170 | 180 | 190 |
| **Welding Speed** | S | mm/sec. | 2 | 4 | 6 |
| **Gas flow rate** | $F_r$ | Lit./min. | 8 | 10 | 12 |

Taguchi method is the most efficient method in which many control parameters can be studied simultaneously without making the experiment very large. However, the application of the Taguchi method is limited to the solution of single response only and for multi-response problems, it relies on the judgment of people involved with the process and usually leads to a solution. The Utility method is useful for dealing with multi-response problems.

The experimental design is completed using the Taguchi's orthogonal array design matrix. In the present experiment situation, three factors are varied during the experiment. Three factors (current, gas flow rate and speed) are varied at three levels as shown in Table 3.4. A possible matrix for studying a combination of three factors and three levels is a nine trial orthogonal array labelled as $L_9$ matrix. The final form of the $L_9$ orthogonal array that is developed for conducting the trials is represented in Table.5.

**Orthogonal Array**

The Taguchi method utilizes orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments. The conclusions drawn from small-scale experiments are valid over the entire experimental region spanned by the control factors and their level settings. However, Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects. The orthogonal array is shown in Table 6.

*Table.6: Taguchi's $L_9$ orthogonal array design.*

| Sr. No. | I | S | $F_r$ |
|---|---|---|---|
| **1** | 1 | 1 | 1 |
| **2** | 1 | 2 | 2 |
| **3** | 1 | 3 | 3 |
| **4** | 2 | 1 | 2 |
| **5** | 2 | 2 | 3 |
| **6** | 2 | 3 | 1 |
| **7** | 3 | 1 | 3 |
| **8** | 3 | 2 | 1 |
| **9** | 3 | 3 | 2 |

**Signal-to-noise ratio**

Taguchi proposed the concept of a signal-to-noise (S/N) ratios meant to be used as measures of the effect of noise factors on target characteristics.

**Larger-the-better**

$$\text{S/N ratio} = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Where n = number of experiments

$y$ = observed data at i, this equation is used for solving problems where maximization of the performance characteristic is desired.

**Smaller-the-better**

$$\text{S/N ratio} = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

This equation is used for solving problems where minimization of the performance characteristic is desired.

**Nominal-the-best**

$$\text{S/N ratio} = -10 \log_{10}\left(\frac{\mu^2}{\sigma^2}\right)$$

Where, $\mu$ = mean

$\sigma$ = Standard deviation

This equation is called nominal-the-best which is used for the problem where minimization of the mean squared error around a specific value is sought.

## DESIGN

**1 Microstructure of Base metal**

In this Figure, the darker colonies are pearlite which is composed of alternating layers of alpha-ferrite (88 wt.

%) and cementite (12 wt. %). The light colour region of the microstructure is the ferrite. The grain boundaries between the ferrite grains can be seen quite clearly. The dark regions are the pearlite.

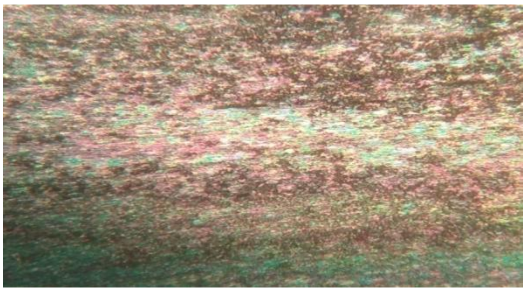


***Figure.6: Microstructure of base metal (mild steel)***

*Table.7: Mechanical properties of base metal (mild steel.*

| Material | Ultimate tensile strength (MPa) | Impact toughness (J) | Hardness (HRC) |
|---|---|---|---|
| **Mild Steel** | 243 | 60 | 55 |

**2 Process parameter optimization of Tungsten inert gas welding**

Process parameters during this experiment with their notations, unit and values at different levels are listed in Table 8.

*Table.8: Tungsten inert gas welding process parameters*

| Parameters | Notation | Unit | Level Of Factors | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| Welding Current | I | Amp. | 170 | 180 | 190 |
| Welding Speed | S | mm/sec. | 2 | 4 | 6 |
| Gas flow rate | $F_r$ | Lit./min. | 8 | 10 | 12 |

Experimental data related to reinforcement, penetration and depth to width ratio have been furnished in Table No. 4.3 for mild steel. All these data have been utilized for analysis and evaluation of optimal parameter combination required to achieve desired weld quality in terms of bead geometry within experimental domain.

**4.3 Evaluation of S/N ratio**

The Hardness, Reinforcement, Penetration and depth to width ratio of specimens is calculated after making specimen and light optical microscopy to find microstructure of specimen. Signal to noise ratio represents the desirable and undesirable values for the output characteristics respectively. The Taguchi method uses S/N ratio to measure the quality characteristics deviating from desired values. The S/N ratio calculated from Minitab 14 software differs for different quality characteristics. In the present study reinforcement, penetration and depth to width ratio of weld specimen is response value. For Reinforcement lower-the-better (LB) and Penetration, depth to width ratio higher-the-better

*Table 9: Experimental data for MS*

| Exp. No. | Mild Steel | | | |
|---|---|---|---|---|
| | Hardness (HRC) | Reinforcement (mm) | Penetration (mm) | Depth to Width Ratio |
| 1 | 46 | 0.94 | 2.76 | 0.50 |
| 2 | 41 | 0.61 | 1.80 | 0.62 |
| 3 | 43 | 0.53 | 1.35 | 0.36 |
| 4 | 49 | 0.77 | 3.25 | 1.04 |
| 5 | 35 | 0.60 | 3.55 | 0.85 |
| 6 | 50 | 1.03 | 2.72 | 0.48 |
| 7 | 55 | 1.42 | 2.98 | 0.50 |
| 8 | 53 | 1.07 | 3.35 | 0.56 |
| 9 | 56 | 1.05 | 3.02 | 0.65 |

(HB) or larger the better (LB) criterion has been selected for analysis.

For Reinforcement, lower-the-better (LB), S/N Ratio $\eta = -10\ln\frac{1}{n}\sum_{i=1}^{n} y_i^2$

For Penetration and depth to width ratio, higher-the-better (HB),

S/N Ratio: $\eta = -10\ln\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$

Where,

$y_i$ represents the experimentally observed value of the $i^{th}$ experiment,

n is the number of repetition for an experimental combination.

**4.3.1 Main effects plot for means and S/N Ratio**

The main effect plots for means are shown in figure. The analysis is made with the help of a Minitab 14. This plot shows the variation of reinforcement, penetration and depth to width ratio with three parameters (welding current, welding speed, gas flow rate). In the plots, x-axis indicates the value of each process parameter (three levels) and y-axis indicates the mean value of reinforcement, penetration and depth to width ratio. The main effects plots are used to determine the optimal design conditions to obtain the optimum reinforcement, penetration and depth to width ratio.

**RESULT**

**1 Hardness**

All the specimens prepared for bead geometry study in as hard faced condition were used for hardness study. To measure the hardness of the weld metals, the top surface of the specimens was ground flat. The welds were also subjected to Rockwall hardness tests. A diamond indenter with 100 kgf load was used to make indentations on all the specimens. The tests were conducted on the weld and HAZ areas at 0.5 mm intervals from center of WZ to base metal covering HAZ. In all of the tested pieces, the hardness values in the weld zone were different due to alloying element but when test moved through HAZ from fusion line to base material, hardness values were higher than in the weld zone.

*Table 10: Experimental data for Hardness*

| Trial No. | Welding Current (Amp.) | Welding Speed (mm/sec.) | Gas flow rate (Ltr. /min.) | Hardness |
|---|---|---|---|---|
| **1** | 170 | 2 | 8 | 46 |
| **2** | 170 | 4 | 10 | 41 |
| **3** | 170 | 6 | 12 | 43 |
| **4** | 180 | 2 | 10 | 49 |
| **5** | 180 | 4 | 12 | 35 |
| **6** | 180 | 6 | 8 | 50 |
| **7** | 190 | 2 | 12 | 55 |
| **8** | 190 | 4 | 8 | 53 |
| **9** | 190 | 6 | 10 | 56 |

*Table 11: Experimental data for Hardness S/N ratio*

| Trial No. | Welding current (Amp.) | Welding speed (mm/sec.) | Gas flow rate (Ltr. /min.) | S/N ratio |
|---|---|---|---|---|
| **1** | 170 | 2 | 8 | -33.2552 |
| **2** | 170 | 4 | 10 | -32.2557 |
| **3** | 170 | 6 | 12 | -32.6694 |
| **4** | 180 | 2 | 10 | -33.8039 |
| **5** | 180 | 4 | 12 | -30.8814 |
| **6** | 180 | 6 | 8 | -33.9794 |
| **7** | 190 | 2 | 12 | -34.8073 |
| **8** | 190 | 4 | 8 | -34.4855 |
| **9** | 190 | 6 | 10 | -34.9638 |

*Table 12: Experimental data for hardness rank*

| **Parameter** | **Level 1** | **Level 2** | **Level 3** | **Delta = Maximum — Minimum** | **Rank** |
|---|---|---|---|---|---|
| Welding Current | - 32.73 | - 32.89 | - 34.75 | 2.03 | 1 |
| Welding Speed | -33.96 | -32.54 | -33.87 | 1.41 | 2 |
| Gas flow rate | -33.91 | -33.67 | -32.79 | 1.12 | 3 |

From the above experiments table it is observed that for hardness shows that mean value increased with increase welding current from 170 Amp to 190 Amp. as shown and decrease in welding speed from 2 to 4 mm/Sec. and then increased from 4 to 6 mm/sec, but decrease from 8 Ltr./min. to 12 Ltr./min. in case of gas flow rate. In case of S/N ratio, the S/N ratio decrease with the increase of welding current from 170 Amp to 190 Amp. as shown and increase in welding speed from 2 to 4 mm/sec. and then decrease from 4 to 6 mm/sec., but increase from 8 Ltr./min. to 12 Ltr./min. in case of gas1 flow rate. The optimal result for hardness is welding current at 170 Amp, welding speed at 4 mm/sec and gas flow rate at 12 Ltr. /min

**2.Penetration**

Weld bead penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. More the penetration, the less is the number of welding passes required to fill the weld joint which consequently results in higher production rate. The effect of welding input parameters on penetration of the weld joint is discussed as below:

*Table 13: Experimental data for penetration.*

| **Trial No.** | **Welding current (Amp.)** | **Welding speed (mm/sec.)** | **Gas flow rate (Ltr. /min.)** | **Penetration (mm)** |
|---|---|---|---|---|
| 1 | 170 | 2 | 8 | 2.84 |
| 2 | 170 | 4 | 10 | 1.90 |
| 3 | 170 | 6 | 12 | 1.40 |
| 4 | 180 | 2 | 10 | 3.25 |
| 5 | 180 | 4 | 12 | 3.60 |
| 6 | 180 | 6 | 8 | 2.78 |
| 7 | 190 | 2 | 12 | 3.00 |
| 8 | 190 | 4 | 8 | 3.45 |
| 9 | 190 | 6 | 10 | 2.59 |

*Table 14: Experimental data for penetration S/N ratio.*

| **Trial No.** | **Welding current (Amp.)** | **Welding speed (mm/sec.)** | **Gas flow rate (Ltr. /min.)** | **S/N ratio** |
|---|---|---|---|---|
| 1 | 170 | 2 | 8 | 9.0664 |
| 2 | 170 | 4 | 10 | 5.5751 |
| 3 | 170 | 6 | 12 | 2.9226 |
| 4 | 180 | 2 | 10 | 10.2377 |
| 5 | 180 | 4 | 12 | 11.1261 |
| 6 | 180 | 6 | 8 | 8.8809 |
| 7 | 190 | 2 | 12 | 9.5424 |
| 8 | 190 | 4 | 8 | 10.7564 |
| 9 | 190 | 6 | 10 | 8.2660 |

*Table 15: Experimental data for penetration rank*

| Parameter | Level 1 | Level 2 | Level 3 | Delta = Maximum — Minimum | Rank |
|---|---|---|---|---|---|
| Welding current | 5.855 | 10.082 | 9.522 | 4.227 | 1 |
| Welding speed | 9.615 | 9.153 | 6.690 | 2.926 | 2 |
| Gas flow rate | 9.568 | 8.026 | 7.864 | 1.704 | 3 |

data it is observed that for penetration shows that mean value increase with increase welding current from 170 Amp to 180 Amp after that decrease from 180 Amp to 190 Amp as shown and decrease in welding speed from 2 to 6 mm/sec., but decrease from 8 Ltr./min. to 10 Ltr./min. and after that increase from 10 Ltr./min. to 12 Ltr./min. in case of gas flow rate. In case of S/N ratio, the S/N ratio increase with increase of welding current from 170 Amp. to 180 Amp after that decrease from 180 Amp to 190 Amp as shown and continuously decrease in welding speed from 2 to 6 mm/sec., but also decrease from 8 Ltr./min. to 12 Ltr./min. in case of gas flow rate. The optimal results for penetration are welding current at 180 Amp welding speed at 2 mm/sec and gas flow rate at 8 Ltr. /min.

*Table 16: ANOVA result for hardness.*

| Source | DOF | Seq SS | Adj SS | Adj MS | F | P | % Contribution |
|---|---|---|---|---|---|---|---|
| Welding Current | 2 | 230.222 | 230.222 | 115.111 | 14.19 | 0.066 | 65.34% |
| Welding Speed | 2 | 93.556 | 93.556 | 46.778 | 5.77 | 0.148 | 94.75% |
| Gas flow rate | 2 | 48.222 | 48.222 | 24.111 | 2.97 | 0.252 | 12.86% |
| Error | 2 | 16.222 | 16.222 | 8.111 | | | |
| Total | 8 | 388.222 | | | | | |

*Table 17: ANOVA result for penetration*

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | % Contribution |
|---|---|---|---|---|---|---|---|
| Welding Current | 2 | 2.326 | 2.326 | 1.163 | 3.93 | 0.081 | 56.69% |
| Welding Speed | 2 | 1.128 | 1.128 | 0.564 | 1.14 | 0.381 | 27.49% |
| Gas flow rate | 2 | 0.331 | 0.331 | 0.166 | 0.26 | 0.777 | 8.07% |
| Error | 2 | 2.842 | 2.842 | 0.4736 | | | |
| Total | 8 | 6.627 | | | | | |

N-l degree of freedom corresponds to the N-l independent comparisons which can be made with N observations. Similar as factorial experiments which are designed to enable comparisons to be made between the responses to the different combinations, these comparisons can be associated with the degree of freedom occurring in the analysis of variance.

Sum of square (MS) = $\frac{\text{Sum of Square (SS)}}{\text{Degree of freedom (DF)}}$

$F_{calculated} = \frac{\text{MS for any term (main orcombined effect)}}{\text{MS for error term}}$

Where, F is called the variance ratio.

A factor is said to have a significant effect on a response if the tabulated F value becomes less than the calculated F value. ANOVA has been performed in the statistical software package MINITAB. It uses the P value, termed as the probability of significance. P-value is calculated based on calculated based on calculated F-value. P-value is obtained then compared with the Alpha-level. The alpha-level depends on the confidence level chosen. If the P-value appears less than 0.05, then it can be concluded that the corresponding factor which influence on the selected response at 95% confidence level.

## CONCLUSION

In this study, parameter optimization has been done to find the optimal parameter. It has been found that current is the most important factor that affects the performance characteristics. The Taguchi method is very efficient for process optimization that can be performed in a limited number of experiments run. The main effect plots give the optimal level for each optimal process parameter. ANOVA is used to find the % contribution of each process parameter in the performance characteristic. However, it is realized that there are no single techniques that appear to be superior in solving a different kind of problem. From the experiment of TIG welding of mild Steel plate following conclusion can be made with the activated welding system.

- Hardness and Penetration of the weld depend on the welding parameters like welding current, welding speed and gas flow rate.
- The optimum values of process parameters for hardness of weld specimens are 170 Amp welding current, 4 mm/sec. welding speed, and 12 lit/min. gas flow rate.
- The optimum values of process parameters for penetration of weld specimens are 180 Amp welding current, 2 mm/Sec. welding speed, and 8 lit/min. gas flow rate.
- Welding current is important factor that affects reinforcement and penetration because more contribution for experiment runs.
- Welding speed is important factor that affects hardness because more contribution for experiment runs.
- Gas flow rate is important factor that affects depth to width ratio because more contribution for experiment runs.

## REFERENCES

[1]. *Welding History, "www.weldinghistory.org," October 2015. [Online]. Available: http://www.weldinghistory.org/whfolder/folder/whpre1800.html. [Accessed 5 June 2019].*

[2]. *Welding Accessories Technology, "www.netwelding.org," 2015. [Online]. Available: http://www.netwelding.com/History%20of%20Welding.html. [Accessed 5 June 2019].*

[3]. *Weldmonger, "http://welding-tv.com/," Weldmonger, 2014. [Online]. Available: http://welding- tv.com/tig-welding-beads-without-filler-rod/. [Accessed 18 July 2019].*

[4]. *Shekhar Srivastava, R. K. Garg, "Process parameter optimization of gas metal arc welding on IS: 2062 mild steel using response surface methodology." Journal of Manufacturing Processes, 25(2017), 296-305.*

[5]. *Pravin Kumar Singh, S. Deepak Kumar, & S. B. Prasad, "Optimization of vibratory welding process parameters using response surface methodology." Journal of Mechanical Science and Technology, 31(5) (2017), 2487-2495.*

[6]. *Nabendu Ghosh, Ramesh Rudrapati, & Gotam Nandi, "Parametric optimization of gas metal arc welding process by using Taguchi method on ferritic stainless steel AISI409." 5th International Conference of materials processing and characterization, 4(2017) 2213-2221.*

[7]. *Nabendu Ghosh, Pradip Kumar Pal, and Goutam Nandi, "Parametric Optimization of MIG Welding on 316L Austenitic Stainless Steel by Grey-Based Taguchi Method." Global Colloquium in Recent Advancement and Effectual Researches in Engineering, Science and Technology 25(2016) 1038-1048.*

[8]. *T. Kannan, B. Senthilkumar, R. Madesh, "Optimization of flux-cored arc welding process parameters by using genetic algorithm." Int J Adv Manuf Technol, DOI 10(2015).1007.*

[9]. *Er Bhawandeep singh, Er Avtar singh, " Performance of activated TIG process in mild steel weld." IOSR Journal of Mechanical and Civil Engineering, Volume 12, Issue 2 Ver. IV(Mar- Apr. 2015), pp 01-05.*

[10]. *Sanjay G. Nayee, Vishvesh J. Badheka, " Effect of Oxide-based fluxes on mechanical and metallurgical properties of dissimilar Activating Flux assisted-Tungsten Inert Gas Welds." Journal of manufacturing Processes, 16(2014) 137-143.*

[11]. *P. Sathiya, P. M. Ajith and R. Soundararajan, "Genetic algorithm based optimization of the process parameters for gas metal arc welding of AISI 904 L stainless steel." Journal of Mechanical Science and technology, 27(8) (2013) 2457-2465.*

[12]. *Biswajit Das, B. Debbarma, R.N. Rai, S.C. Saha, "Influence of process parameters on depth of pentration of welded joint in MIG wlding process", National Institute of Technology, Agartala, India, Volume: 02 Issue: 10(2013).*

[13]. *Vikesh, Prof. Jagjit Randhawa, and Dr. N.M.Suri, "Effect of A-TIG welding process parameters on Penetration in Mild Steel Plates." International Journal of Mechanical and Engineering (IJMIE), Vol.-3, Iss-2: 2231 – 6477(2013).*

[14]. *Raghuvir Singh, Dr. N.M Suri, Prof. Jagjit Randhawa, "Optimization of Process Parameters For TIG welding Process of 304L Stainless Steel using Response Surface Methodology." International Journal of Mechanical Science and Civil Engineering, Volume 2, Issue 2, pp 36-40(2013).*

[15]. *P. Vasantharaja, M. Vasudevan, " Studies on A-TIG welding of Low Activation Ferritic/Martensite(LAFM) steel." Journal of Nuclear Materials, 421(2012) 117-123.*

[16]. *Edwin Raja Dhas J, Jenkins Hexley Dhas S, "A review on optimization of welding process." International Conference on modeling, optimization and Computing, Procedia Engineering 38(2012) 544-554.*

[17]. *Y. Ruan, W.B. Gong, Y.P. Li, " Mechanical properties and microstructures of 6082-T6 joint welded by twin wire metal inert gas arc welding with the $SiO_2$ flux." Materials and design, 35(2012) 20 – 24.*

[18]. *Kuang-hung Tseng, Chih-Yu Hsu, "Performance of activated TIG process in austenitic stainless steel welds." Journal of materials processing technology 211(2011) 503–512.*

[19]. *D.S. Nagesh, G.L. Datta, "Genetic algorithm for optimization of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process." Applied Soft Computing 10(2010), 897-907.*

[20]. *Ugur Esme, Yugut Kazancoglu, & Sueda Ozgun, "Optimization of weld bead Geometry in TIG welding process using grey relation analysis and Taguchi method." MTAEC 43(3) (2009)143.*

[21]. *H.Y. Huang, "Effects of shielding gas composition and activating flux on GTAW weldments." Materials and Design, 30(2009) 2404-2409.*

[22]. *Hidetoshi Fujii, Shanping Lu, Kiyoshi Nogi, "Development of an advanced A-TIG (AA-TIG) welding method by control of Marangoni convection." Materials Science and Engineering, Vol. 495 A, pp. 296-303(2008).*

[23]. *Saurav Datta, Ashish Bandyopadhyay, & Pradip Kumar Pal, "Application of taguchi philosophy for parametric optimization of bead geometry and HAZ width in submerged arc welding using a mixture of fresh flux and fused flux." Int J Adv. Manufacturing and Technology, 36(2008) 689-698.*