*International Journal of Engineering Research and Development*
*eISSN : 2278-067X, pISSN : 2278-800X, www.ijerd.com*
*Volume 4, Issue 8 (November 2012), PP. 42-56*

# Some Studies on Mig Hardfacing Of Mild Steel Components

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***Abstract:—***Metal parts often fail their intended use not because they fracture, but because they wear, which causes them to lose dimension and functionality. Different categories of wear exist, but the most typical modes are – Abrasion, Impact, Metallic (metal to metal), Heat, Corrosion etc. Most worn parts don't fail from a single mode of wear, such as impact, but from a combination of modes, such as abrasion and impact etc. Hardfacing is the deposition of material on the base material, the filler material which is deposited is harder than the base material by MIG welding. In this paper Taguchi Technique is used for the project work and were different welding parameters are considered Voltage, wire feed rate, nozzle to plate distance, welding speed and the gas flow rate. L25 an orthogonal array is generated and the work is carried out by as per L25 design matrix. The hardfaced plate is cut at centre The work piece is polished in different emery papers, and polished on cloth. The specimen is etched is 2% Nital solution. Different beads we observed and also the microstructure are observed in light optical microscope,. The specimen is taken for Hardness test the hardness of the each samples are measured the hardness value is increased from range between 16 to 20 HRC and also the impact –charpy test is conducted. the toughness value is measured for each samples and the toughness value is increased and is in the range from 16 to 20Kgm.
***Keywords:—***hardfacing, mig welding, Taguchi technique, hardness, impact test

## I. INTRODUCTION

Wear is the predominant factor that controls the life of any machine part. Metal parts often fail their intended use not because they fracture, but because they wear, which causes them to lose dimension and functionality. Different categories of wear exist, but the most typical modes are – Abrasion, Impact, Metallic (metal to metal), Heat, Corrosion etc. Most worn parts don't fail from a single mode of wear, such as impact, but from a combination of modes, such as abrasion and impact etc. Research is going on over years to reduce the wear either in the form of using a new wear resistant material or by improving the wear resistance of the existing material by addition of any wear resistant alloying element etc. Many methods are in practice. In the last years hardfacing became an issue of intense development related to wear resistant applications.

This process has been adopted across many industries such as Cement, Mining, Steel, Petro-chemical, Power, Sugar cane and Food [Kirchgaßner et al., (2008)].
There are various welding processes for hardfacing. They can be grouped in the following ways:

**1. Hardfacing by Arc Welding –**
Shielded Metal Arc Welding [Amado et al., (2008)], Flux Cored Arc Welding [John J. Coronado et al., (2009)], Submerged Arc Welding [Chang et al., (2003)].

**2. Hardfacing by Gas Welding -** Deposition by Oxy-Acetylene Gas Welding [Buchely et al., (2005)].

**3. Hardfacing by combination of Arc and Gas** - Tungsten Inert Gas Welding [Kashani et al., (2007)], Gas Metal Arc Welding [Fouilland et al., (2009)].

**4. Powder Spraying** - Flame Spraying [Navas et al., (2006)], High Velocity Oxy-Fuel Process [Lin M.C. et al.(2006)], Electric Arc Spraying [Vernon E. Buchanan, (2009)], Plasma Transferred Arc [D'Oliveira et al.,(2002)] etc.

**5.Laser Hardfacing** (Laser Cladding) [Qian Ming et al., (1998)].

**Weld Consumables**
Many different hard-facing alloys are available. They fall into four general categories:

**1. Low-alloy iron-base alloys** materials containing up to 12% alloy components, usually chromium [Berns et al., (1997)], molybdenum and manganese [Jun–ki et al., (2001)].

**2.High-alloy iron-base alloys** materials with 12-50% alloy content; in addition to the chromium found in all iron- base hard-facing alloys, some of these alloys may also contain nickel [EL Mansori et al., (2007)] or cobalt [Fouilland et al., (2009)].

**3. The cobalt-base** [Fouilland et al., (2009)] and nickel-base alloys [EL Mansori et al., (2007)], which contain relatively small amounts of iron (1.3 to 12.5%). Of these, the most costly, but also the most versatile, are the cobalt-chromium-tungsten alloys

**4. Tungsten carbide materials** [Blombery et al, (1974)]. Tungsten carbide is one of the hardest materials available for industrial use. It cannot be melted by any flame. It is also rather brittle. For hard-facing purposes, it is crushed and applied in conjunction with a "binding" metal.

**Base Materials**

Almost 85% of the metal produced and used is steel. The term steel encompasses many types of metals made principally of iron. The various types of steels used in the industry for making different components for different applications are grouped in to the following types:

**1. Low-Carbon Steels and Low-alloy Steels -** These steels include those in the AISI series C-1008 to C-1020 [Wang et al., (2008)]. Carbon ranges from 0.10 to 0.25%, manganese ranges from 0.25 to 1.5%, phosphorous is 0.4% maximum, and sulfur is 0.5% maximum. Steels in this range are most widely used for industrial fabrication and construction.

**2. Medium-Carbon Steels** - These steels include those in the AISI series C-1025 to C-1050 [Wang et al.,(2005)]. The composition is similar to low-carbon steels, except that the carbon ranges from 0.25 to 0.50% and manganese from 0.60 to 1.65%. Medium-carbon steels are readily wieldable provided some precautions are observed.

**3. High-Carbon Steels** - These steels include those in the AISI series from C-1050 [Kwok et al., (2001)] to C-1095. The composition is similar to medium-carbon steels, except that carbon ranges from 0.30 to 1.00%.

**4. Other steels are Low-Nickel Chrome Steels** (AISI 3120, 3135, 3140, 3310, and 3316), Low-Manganese Steels (AISI 1320, 1330, 1335, 1340, and 1345).

**MIG welding.**

The metal arc inert gas shielded process also known as MIG, [MAGS] Metal Arc Gas Shielding and [GMAW] Gas Metal Arc Welding, All commercially important metals such a carbon steel ,high strength steels, low alloy steels, stainless steels , Aluminum, copper, Titanium and Nickel alloys can be welded in all positions with GMAW by choosing a appropriate shielding gas electrode and welding variables.It offers advantage of high welding speeds, smaller heat affected zone than TIG welding, excellent oxide film removal during welding. For these reasons MIG welding is the most widely used.

**Shielding Gases.**

The gases used are combinations of two or more gases some of them are, Argon Carbon dioxide, Helium and oxygen.

In most welding application a combination of Argon and Carbon dioxide gas is used. Argon gas produces a clear weld and carbon dioxide help to produce deeper penetration.

100% Carbon dioxide.
25% Carbon dioxide and 75% Argon.
2% carbon dioxide and 98% Argon.

Argon is used for welding of Aluminum, copper, Nickel, Titanium

**Electrodes.**

The commonly used electrode for Mild Steel is ER70S-6.

ER—stands for filler electrode.

70—Strength of the weld in case of mild steel, the weld has a minimum of 70.000pound tensile strength per square inch of the weld.

S—stands for solid rod.

6- represent s the amount of cleaner added to the wire to improve the weld quality.

Electrode Diameter : 0.8mm,0.9mm, 1.0mm, 1.2mm,1.6mm.

CO2 gas-shield welding wireER70s-6 has excellent mechanical performance such as depositing speed and high efficiency, stable arc, little splash , good welding seam. This series of welding wires are suitable for the low carbon steel and low alloy structure, vehicle, bridge container , construction machinery ,boilers and construction etc. Chemical composition of electrode wire is C[0.06 to 0.15] , Mn [1.4 to 1.85], Si[0.80 to 1.15] ,P <= 0.025, S <= 0.035, Cu <= 0.35, Ni <= 0.30, r<= 0.20. This is an alloy electrode , hard faced layer are resistant to wear and they are also resistant to medium impact during exploitation. This hard faced electrode is especially suitable for hard facing of parts exposed to friction of metals to minerals. This electrode is highly resistant to abrasive wear At relatively low current GMAW operates in the globular metal transfer mode. It is characterized by periodic formation of big droplets at the end of electrodes, whch detach due to gravitational force into the weld pool. This metal transfer mode suffers from lack of control over molten droplets and arc instability due to formation of big droplets. At higher currents, the process transits to spray mode. This mode offers high deposition rate but due to tapering of electrode smaller diameter drops are formed. Continuous metal deposition, in form of drops, produces smooth bead and stiffer arc. Drawbacks of this metal transfer mode are:

Minimum current for spray mode's being too high for some materials, large heat input to work piece, wide bead, and only down hand positional capability. It offers advantage of high welding speeds, smaller heat affected zone than TIG welding, excellent oxide film removal during welding. For these reasons MIG welding is the most widely used.

**Taguchi Method** Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on " Orthogonal Array " experiments which gives much reduced " variance " for the experiment with " optimum settings " of control parameters. Taguchi method is significantly disciplined mechanism for evaluating and implementing improvement in products, processes, materials, equipments and facilities. These improvement are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best result.

Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, *i.e.* the lower-the-better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic.

This method is applicable over a wide range of engineering fields that include processes which manufacture raw materials, sub systems, products for professional and consumer markets. Infact the method can be applied to any processes be it engineering fabrication , CAD, banking and service sectors etc.

## II. METHODOLOGY ADOPTED

**Taguchi method**In Taguchi Method, the word "optimization" implies "determination of BEST levels of control factors". In turn, the BEST levels of control factors are those that maximize the Signal-to-Noise ratios. The Signal-to-Noise ratios are log functions of desired output characteristics. The experiments, that are conducted to determine the BEST levels, are based on "Orthogonal Arrays", are balanced with respect to all control factors and yet are minimum in number. This in turn implies that the resources (materials and time) required for the experiments are also minimum.

Taguchi method divides all problems into 2 categories - STATIC or DYNAMIC. While the Dynamic problems have a SIGNAL factor, the Static problems do not have any signal factor. In Static problems, the optimization is achieved by using 3 Signal-to-Noise ratios - smaller-the-better, larger-the-better and nominal-the-best. In Dynamic problems, the optimization is achieved by using 2 Signal-to-Noise ratios - Slope and Linearity. Taguchi Method is a process/product optimization method that is based on 8-steps of planning, conducting and evaluating results of matrix experiments to determine the best levels of control factors. The primary goal is to keep the variance in the output very low even in the presence of noise inputs. Thus, the processes/products are made ROBUST against all variations.

The optimization of welding parameters in the hard facing operation by GMAW by using hybrid Taguchi techniques like .
1: Orthogonal Array (OA). 2: Grey relational Analysis. 3: Desirability Function (DF).
The mechanical behavior of metals in SAW and bead geometry optimization can be done by using the following Taguchi techniques. 1: Orthogonal Array (OA). 2: Signal to Noise ratio (S/N ratio). 3: Analysis of variance (ANOVA)

**Theory of Grey relational analysis**

In Grey relational analysis, experimental data i.e., measured features of quality characteristics are first normalized ranging from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated which would result in the highest grey relational grade. The optimal factor setting for maximizing overall grey relational grade can be performed by Taguchi method
In Grey relational generation the normalized bead width, reinforcement height, corresponding to **larger- the- better** criterion can be expressed as

$$X_i(k) = \frac{Y_i(k) - \text{Min } Y_i(k)}{\text{Max } Y_i(k) - \text{Min } Y_i(k)}$$

Depth of penetration and depth of HAZ should follow ***lower-the-better*** criterion, which can be expressed as

$$X_i(k) = \frac{\text{Max } Y_i(k) - Y_i(k)}{\text{Max } Y_i(k) - \text{Min } Y_i(k)}$$

Where xi (k) is the value after the grey relational generation min yi (k) is the smallest value of yi(k) for the kth response. The normalized data after grey relational generation are tabulated.
The grey relational coefficient can be calculated as

$$\xi_i(k) = \frac{\Delta_{min} + \Psi \Delta_{max}}{\Delta_{oi}(k) + \Psi \Delta_{max}}$$

Where **$\Delta$oi = II Xo (k) - Xi (k) II,** **$\Delta$min = II xo (k) – xj(k) I**I smallest value of **$\Delta$oi,** **$\Delta$max = II Xo (k) – Xi (k) II** largest value of $\Delta$oi After averaging the grey relational coefficients. The grey relational grade $\gamma$i can be computed as

$$\gamma i = 1/n \ \Sigma \xi i(k)$$

Where n = number of process responses. The highest value of grey relational grade corresponds to intense relational degree between the reference sequence xo(k) and the given sequence(k). The reference sequence xo (k) represents the best process sequence therefore higher grey relational grade means that the corresponding parameter combination is closer to the optimal. The mean response for grey relational grade with its grand mean and the main effect plot of grey relational grade are very important because optimal process condition can be evaluated from this plot.

## III. EXPERIMENTAL PROCEDURE

Metal Inert Gas Welding is a multi-factor metal fabrication and surfacing technique. various process parameters influencing bead geometry, bead quality as well as mechanical-metallurgical characteristics of the surfaced metal includes the welding current, voltage, wire feed rate, electrode traverse speed, nozzle to plate distance, gas flow rate etc. in full factorial design the number of experimental runs are exponentially increases as their levels increases. This results high experimental cost and time so in order to avoid this situation and to search the optimal process condition through a limited number of experimental runs. the present work has been planned to use five conventional process control parameters like Voltage(V), Wire feed rate (W), Welding Speed(S) Nozzle to plate distance(N) and GAS flow rate [G] are varied at five different levels.

Taguchi's L25 orthogonal array has been selected to restrict the number of experimental runs. Experiments have been conducted with these process control parameters to obtain bead-on-plate surfacing on mild steel plates of thickness of dimension [50 x 100 x 08 ] mm by MIG Welding(MIG). Design matrix has been selected based on Taguchi's L25 orthogonal array consisting 25 sets of coded condition.

**Table No:01** MIG welding process parameter and their limits

| | **Notations** | **Levels** | | | | | **Units** |
|---|---|---|---|---|---|---|---|
| **Variables** | | 1 | 2 | 3 | 4 | 5 | |
| Wire feed range | **W** | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | Ipm |
| Arc Voltage | **V** | 30 | 32 | 34 | 36 | 38 | Volts |
| Nozzle to Plate Distance | **N** | 08 | 10 | 12 | 14 | 16 | Mm |
| Welding speed | **S** | 10 | 13 | 18 | 21 | 25 | Sec/cm |
| Gas flow rate | **G** | 10 | 13 | 18 | 21 | 25 | Lit/min |

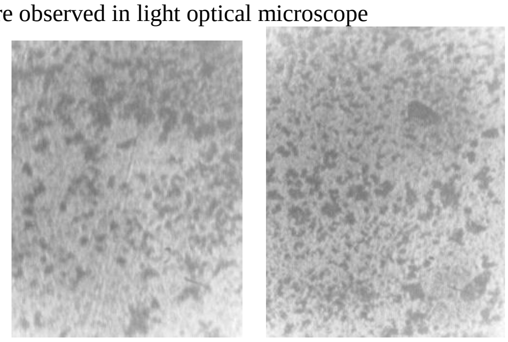
***Fig : 1*** *showing cutting section of the hardfaced plates.*

**Table 2:** Design matrix of the experiment showing Levels of Factorial

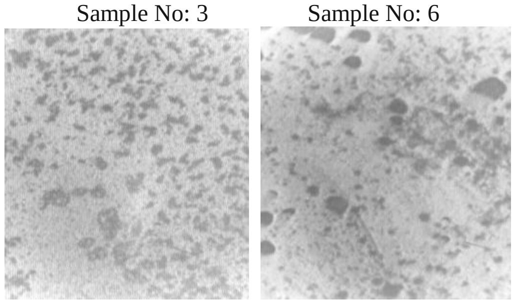
| Sample No | W wire feed rate | V Voltage | N nozzle to plate | S welding speed | G Gas flow rate |
|---|---|---|---|---|---|
| 01 | 1 | 1 | 1 | 1 | 1 |
| 02 | 1 | 2 | 2 | 2 | 2 |
| 03 | 1 | 3 | 3 | 3 | 3 |
| 04 | 1 | 4 | 4 | 4 | 4 |
| 05 | 1 | 5 | 5 | 5 | 5 |
| 06 | 2 | 1 | 2 | 3 | 4 |
| 07 | 2 | 2 | 3 | 4 | 5 |
| 08 | 2 | 3 | 4 | 5 | 1 |
| 09 | 2 | 4 | 5 | 1 | 2 |
| 10 | 2 | 5 | 1 | 2 | 3 |
| 11 | 3 | 1 | 3 | 5 | 2 |
| 12 | 3 | 2 | 4 | 1 | 3 |
| 13 | 3 | 3 | 5 | 2 | 4 |
| 14 | 3 | 4 | 1 | 3 | 5 |
| 15 | 3 | 5 | 2 | 4 | 1 |
| 16 | 4 | 1 | 4 | 2 | 5 |
| 17 | 4 | 2 | 5 | 3 | 1 |
| 18 | 4 | 3 | 1 | 4 | 2 |
| 19 | 4 | 4 | 2 | 5 | 3 |
| 20 | 4 | 5 | 3 | 1 | 4 |
| 21 | 5 | 1 | 5 | 4 | 3 |
| 22 | 5 | 2 | 1 | 5 | 4 |
| 23 | 5 | 3 | 2 | 1 | 5 |
| 24 | 5 | 4 | 3 | 2 | 1 |
| 25 | 5 | 5 | 4 | 3 | 2 |

The experiments have been performed by MIG Welding Machine. ACESS MIG 400 Copper coated electrode wire of diameter 1.2mm [ AWS **ER 70S-6 ]** and Gases used are Argon 98% and CO2 2% . After surfacing transverse sections of the weld bead have been cut from the middle portions of the plates by grinding cutting machine.
The specimens have been polished by fine abrasive papers followed by the emery papers of grades1, 1/0, 2/0, 3/0 and 4/0 finally they have been smoothened by means of cloth polishing. The properly polished specimens have been etched with 2% Nital solution for about 30 sec duration.

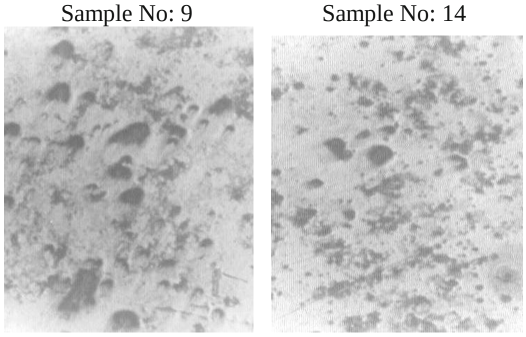
The specimen have been prepared ready for further metallurgical investigations and analysis bead geometry and HAZ in terms of Bead Width, Height of Reinforcement, Depth of Penetration and Depth of HAZ. Have measured by Optical Triangular Metallurgical Microscope Data related to bead geometry and HAZ have been measured or recorded in the table shown below.
The Microstructure of the sample are observed in light optical microscope



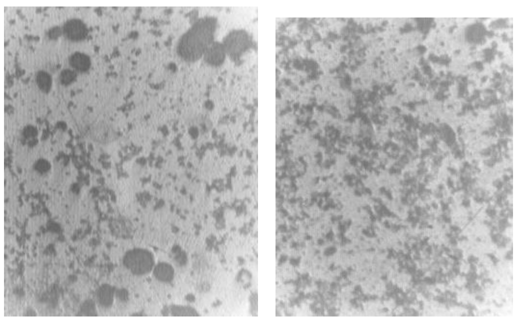
Sample No: 3 Sample No: 6



Sample No: 9 Sample No: 14



Sample no:18 Sample No :20



Sample No :23 sample No:25

***Fig2:*** *Microstructure of the specimens shown*

**Hardness measurement:**

The hardness of the surfaced samples is found out both at surface and cross section by the Rockwell hardness testing machine with diamond cone as an indenter. The minimum load applied is 10kg and the maximum load is 150kg for the time duration of 06 seconds. The scale used for the samples before surfacing is Scale-C and for the samples after hardfacing Scale-C was used. The hardness values for the samples are tabulated in the tables 11 and 12

**Procedure of the Rockwell Test**

Take the given specimen and clean the surfaces of specimen and place the specimen so that its surface is normal to the direction of applied load , the lever should be normal position ( without hand) . The Diamond Penetrator is fixed in the holder of hardness machine. Raise the main screw such that the specimen just make in contact with intender, first it will take minor load of 10 Kg then a small pointer starts rotating when it connect the red spot apply the measure load for diamond intender for a period of 15 to 20 sec and then slowly released the load and note down the hardness num of from dial gauge and tabular the values in the tabular column. The scale used for hardness is HRC.

**The Charpy Test** While most commonly used on metals, it is also used on polymers, ceramics and composites. The Charpy test is most commonly used to evaluate the relative toughness or impact toughness of materials and as such is often used in quality control applications where it is a fast and economical test. It is used more as a comparative test rather than a definitive test.**Charpy Test Specimens :** specimens normally measure 55x10x10mm and have a notch machined across one of the larger faces. The notches may be: V-notch – A V-shaped notch, 2mm deep, with 45° angle and 0.25mm radius along the base and U-notch or keyhole notch – A 5mm deep notch with 1mm radius at the base of the notch

## IV. RESULTS AND DISCUSSION

**Table 3: Experimental data**

| Sample No | Sample width (mm) | Bead width (mm) | Height of reinforcement (mm) | Depth of penetration (mm) | Depth of HAZ (mm) | % Dilution |
|---|---|---|---|---|---|---|
| 01 | 45 | 11.2 | .3.5 | 3.0 | 1.4 | 42.8 |
| 02 | 45 | 11.0 | 3.5. | 2.8 | 1.3 | 42.8 |
| 03 | 45 | 12.0 | 2.4 | 2.0 | 1.2 | 50.0 |
| 04 | 40 | 12.4 | 3.5 | 2.9 | 1.2 | 42.5 |
| 05 | 42 | 11.6 | 3.2 | 2.0 | 1.3 | 40.0 |
| 06 | 42 | 10.8 | 3.0. | 1.8 | 1.5 | 41.7 |
| 07 | 42 | 11.2 | 4.4 | 3.3 | 1.4 | 33.3 |
| 08 | 45 | 12.0 | 3.5 | 2.2 | 1.4 | 33.5 |
| 09 | 45 | 12.4 | 4.8 | 3.4 | 1.5 | 37.5 |
| 10 | 50 | 11.8 | 3.5 | 2.8 | 1.4 | 33.3 |
| 11 | 50 | 12.2 | 4.8 | 3.2 | 1.4 | 33.3 |
| 12 | 47 | 11.8 | 5.0 | 4.2 | 1.4 | 33.3 |
| 13 | 45 | 12.2 | 3.8 | 3.0 | 1.3 | 28.5 |
| 14 | 43 | 14.4 | 3.2 | 2.0 | 1.1 | 25.0. |
| 15 | 40 | 13.6 | 8.0 | 4.2 | 1.6 | 30 |
| 16 | 50 | 12.4 | 5.8 | 3.4 | 1.8 | 40 |
| 17 | 50 | 12.2 | 3.0 | 2.0 | 1.2 | 33.3 |
| 18 | 50 | 12.2 | 3.0 | 2.2 | 1.3 | 33.3 |
| 19 | 46 | 14.0 | 2.6 | 1.8 | 1.3 | 33.3 |
| 20 | 50 | 10.8 | 3.4 | 3.0 | 1.4 | 33.3 |
| 21 | 50 | 10.8 | 3.0 | 1.8 | 1.0 | 33.3 |
| 22 | 50 | 12.4 | 3.0 | 1.8 | 1.2 | 33.3 |
| 23 | 50 | 11.6 | 2.8 | 1.4 | 1.2 | 25 |
| 24 | 50 | 13.2 | 6.0 | 3.4 | 1.4 | 30.0 |
| 25 | 50 | 14.4 | 5.8 | 3.5 | 1.3 | 30.0 |

**Table:4 Mean Grey relational grade and Signal to Noise ratio**

| Experiment No | Grey relational grade | Signal to noise(S/N) ratio |
|---|---|---|
| 01 | 0.789 | -2.05 |
| 02 | 0.768 | -2.30 |
| 03 | 0.750 | -2.50 |
| 04 | 0.800 | -1.94 |
| 05 | 0.765 | -2.32 |
| 06 | 0.72 | -2.20 |
| 07 | 0.84 | -1.5 |
| 08 | 0.74 | -2.65 |
| 09 | 0.70 | -3.09 |
| 10 | 0.73 | -2.74 |
| 11 | 0.78 | -2.16 |
| 12 | 0.70 | -3.09 |
| 13 | 0.64 | -3.87 |
| 14 | 0.80 | -1.94 |
| 15 | 0.62 | -4.16 |
| 16 | 0.73 | -2.74 |
| 17 | 0.75 | -2.5 |
| 18 | 0.68 | -3.35 |
| 19 | 0.68 | -3.35 |
| 20 | 0.76 | -2.38 |
| 21 | 0.70 | -3.09 |
| 22 | 0.67 | -3.48 |
| 23 | 0.66 | -3.60 |
| 24 | 0.76 | -2.38 |
| 25 | 0.77 | -2.04 |

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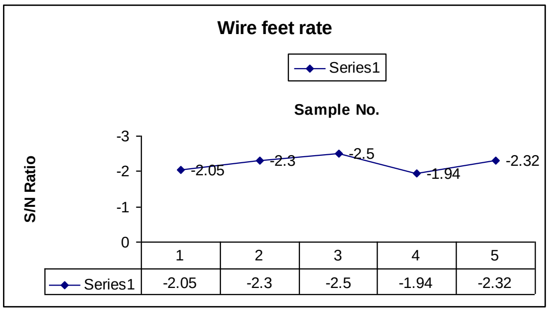


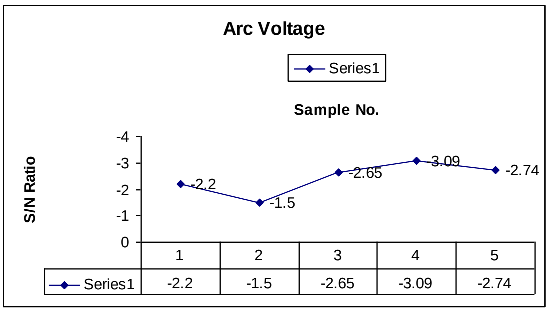

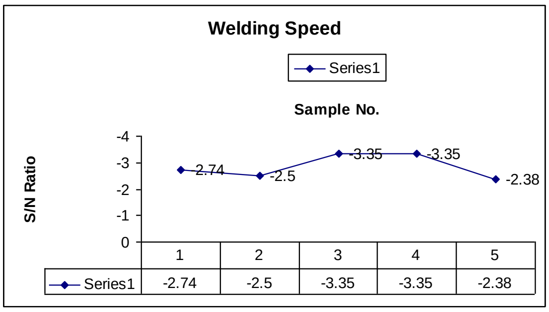


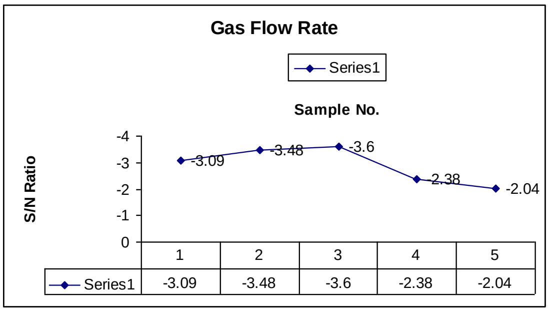


**Table 5 Mean for overall grey relational grade**

| Grey relational grade | | | | | | |
|---|---|---|---|---|---|---|
| **Factor** | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** | **Delta** |
| Arc Voltage | 0.774 | 0.746 | 0.708 | 0.720 | 0.712 | 0.066 |
| Wire feed rate | 0.776 | 0.750 | 0.73 | 0.703 | 0.712 | 0.064 |
| Nozzle to plate distance | 0.769 | 0.756 | 0.706 | 0.715 | 0.715 | 0.054 |
| Welding speed | 0.7785 | 0.755 | 0.740 | 0.707 | 0.712 | 0.0.07 15 |
| Gas flow rate | 0.756 | 0.715 | 0.725 | 0.703 | 0.725 | 0.053 |

For the orthogonal experimental design, it is possible to separate out the effect of each surfacing parameter at different levels. For example the mean grey relational grade for the voltage at levels 1,2,3,4 and 5 can be calculated by averaging the grey relational grades for the experiments 1-5, 6-10, 11-15, 16-20, and 21-25 respectively. And for the wire feed rate 1-4, 5-10, 11-14, 15-20, 21-25 and for the electrode traverse speed 1-3,4-10, 11-13,14-21,22-25 and for nozzle to plate distance 1-2, 3-10, 11-12, 13-20, 21-25 respectively.

Delta = range (maximum – minimum)
Total mean grey relational grade = 0.73196

**Table06: Result of confirmatory experiment**

| **Initial factor setting** | | **Optimal process condition** | |
|---|---|---|---|
| | | **Prediction** | **Experiment** |
| Level of factors | V1W1S1G1N1 | V4W3S3GNPD5 | V1Wf4Tr3NP D5 |
| Bead width | 12mm | 12mm | 12mm |
| Reinforcement height | 4.0mm | 3.2mm | 3.5mm |
| Depth of penetration | 1.1mm | 1.0mm | 1.0mm |
| Depth of HAZ | 1.5mm | 1.2mm | 1.0mm |
| S/N ratio of overall grey relational grade | -1.08 | 0.796 | 0.80 |
| Overall grey relational grade | 0.5260 | 0.9826 | 0.61193 |
| Improvement in grey relational grade | 0.3707 | | |

Note: from the above table it is confirmed that the best optimum values of process control parameters are.
Voltage level **(V4) = 34V**
Wire feed rate level **(W3) = 2.0 ipm**
Electrode traverse speed level **(S3) = 16 sec/cm**
Nozzle to plate distance level **(N3) = 16mm**
Gas flow rate **G3 = 18 lit/min**
Hence optimum setting of parameters **is V3 W4 S3 N5 G3**
**Analysis of Variance**

ANOVA is a statistical tool or technique which can give some important conclusions based on analysis of experimental data. The method is very useful to reveal the level of significance of influence of factors or interaction of factors on a particular response. It separates the total variability of the response.

(Sum of squared deviations about the grand mean) into contributions provided by each of the parameter/factor and the errors. Thus

$$SSt = SSf + SSe$$

Where $SSt = \sum (\mathrm{Ɣ}j - \mathrm{Ɣ}m)^2$
SSt = total sum of squared deviations about the mean
Ɣj = mean response for the jth experiment
Ɣm = grand mean of the response
N = number of experiments in the orthogonal array.
SSf = sum of squared deviations due to each factor.
SSe = sum of squared deviations due to error.

**Table 7: Analysis of variance using adjusted SS for tests**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Voltage | 4 | 0.0030799 | 0.0030799 | 0.0007699 | 0.70 | 0.60 |
| Wire feed rate | 4 | 0.0035022 | 0.0035022 | 0.0008755 | 2.67 | 0.025 |
| Electrod e traverse speed | 4 | 0.0031986 | 0.0031986 | 0.0007996 | 9.72 | 0.42 |
| Nozzle toplate distance | 4 | 0.003798 | 0.003798 | 0.0009495 | 1.68 | 0.212 |
| Gas flow rate | 4 | 0.0018097 | 0.0018097 | 0.0004524 | - | - |
| Error | 4 | 0.00532 | 0.00235 | 0.0000452 | - | - |
| **Total** | **24** | **0.0207084** | **0.0177384** | **0.003122** | **14.77** | **1.255** |

In ANOVA Table 7 mean square deviation is defined as
MS=SS (sum of square deviation) /DF (degrees of freedom)
F = value of Fisher's ratio (variance ratio) is defined as
F = MS for a term / MS for the error term

Depending upon F-value, P-value (probability of significance) is then calculated. if the P-value for a term appears less than 0.05 ( 95% confidence level) then it can be considered that the effect of the factors/interaction of factors is significant on the selected response.

**Table 8. Hardness values of the samples**

| Sample No | Load P=P1+P2 | Before Hardfacing | | After Hardfacing | |
|---|---|---|---|---|---|
| | 10+140 | C Scale | 100-C RHN | C Scale | 100-C RHN |
| 01 | 150 | 28 | 72 | 46 | 54 |
| 02 | 150 | 29 | 71 | 46 | 54 |
| 03 | 150 | 32 | 68 | 45 | 55 |
| 04 | 150 | 34 | 64 | 48 | 52 |
| 05 | 150 | 26 | 74 | 47 | 53 |
| 06 | 150 | 28 | 72 | 48 | 52 |
| 07 | 150 | 29 | 71 | 49 | 51 |
| 08 | 150 | 29 | 71 | 46 | 54 |
| 09 | 150 | 30 | 70 | 47 | 53 |
| 10 | 150 | 32 | 68 | 47 | 53 |
| 11 | 150 | 30 | 70 | 46 | 54 |
| 12 | 150 | 31 | 69 | 46 | 54 |
| 13 | 150 | 31 | 69 | 52 | 48 |
| 14 | 150 | 29 | 71 | 44 | 56 |
| 15 | 150 | 30 | 70 | 46 | 54 |
| 16 | 150 | 28 | 72 | 48 | 52 |
| 17 | 150 | 30 | 70 | 45 | 55 |
| 18 | 150 | 28 | 72 | 45 | 55 |
| 19 | 150 | 29 | 71 | 46 | 54 |
| 20 | 150 | 28 | 72 | 48 | 52 |
| 21 | 150 | 30 | 70 | 46 | 54 |
| 22 | 150 | 32 | 68 | 48 | 52 |
| 23 | 150 | 32 | 68 | 46 | 54 |
| 24 | 150 | 30 | 70 | 48 | 52 |
| 25 | 150 | 29 | 71 | 46 | 54 |

**Table No: 9. Impact test before hardfacing**

| Sample No | Load kg mtr | Energy consumed by aspecimen Before Hardfacing | Energy consumed by a specimen kg mtr After Hard facing |
|---|---|---|---|
| 01 | 30 | 10.2 | 17.6 |
| 02 | 30 | 11.4 | 19.0 |
| 03 | 30 | 11.2 | 19.2 |
| 04 | 30 | 10.8 | 18.8 |
| 05 | 30 | 12.0 | 17.8 |
| 06 | 30 | 12.2 | 18.4 |
| 07 | 30 | 11.6 | 18.6 |
| 08 | 30 | 11.4 | 18.8 |
| 09 | 30 | 11.8 | 18.4 |
| 10 | 30 | 10.8 | 18.6 |
| 11 | 30 | 10.6 | 18.8 |
| 12 | 30 | 12.8 | 19.4 |
| 13 | 30 | 12.6 | 19.0 |
| 14 | 30 | 12.8 | 18.6 |
| 15 | 30 | 12.8 | 19.4 |
| 16 | 30 | 12.4 | 20.0 |
| 17 | 30 | 13.0 | 20.0 |
| 18 | 30 | 13.4 | 20.4 |
| 19 | 30 | 12.8 | 18.8 |
| 20 | 30 | 12.6 | 16.8 |
| 21 | 30 | 12.4 | 16.6 |
| 22 | 30 | 12.0 | 17.4 |
| 23 | 30 | 12.0 | 17.8 |
| 24 | 30 | 12.8 | 17.6 |
| 25 | 30 | 12.8 | 18.2 |

## V. CONCLUSION

In the present study, the detailed methodology of Taguchi optimization technique coupled with Grey relational analysis has been adopted and applied for evaluating parametric combination to achieve acceptable depth of penetration, height of reinforcement, bead width and depth of heat affected zone(HAZ) of the hardfaced welements obtained by using Gas Metallic Arc Welding. The criteria selected for a weldment are to provide lower penetration and increased height of reinforcement, bead width and lower HAZ. To avoid drastic micro-structural changes between the weld metal and HAZ. It was concluded to minimize the HAZ (minimum width and depth of HAZ).in the present study it is also concluded that the hardness of the hardfaced component is more than that of hardness before hardfacing. The difference of the hardness is about 16 to 22 HRC and the toughness value is increased from 18 – 20 Kgm energy consumed to fracture the specimen.

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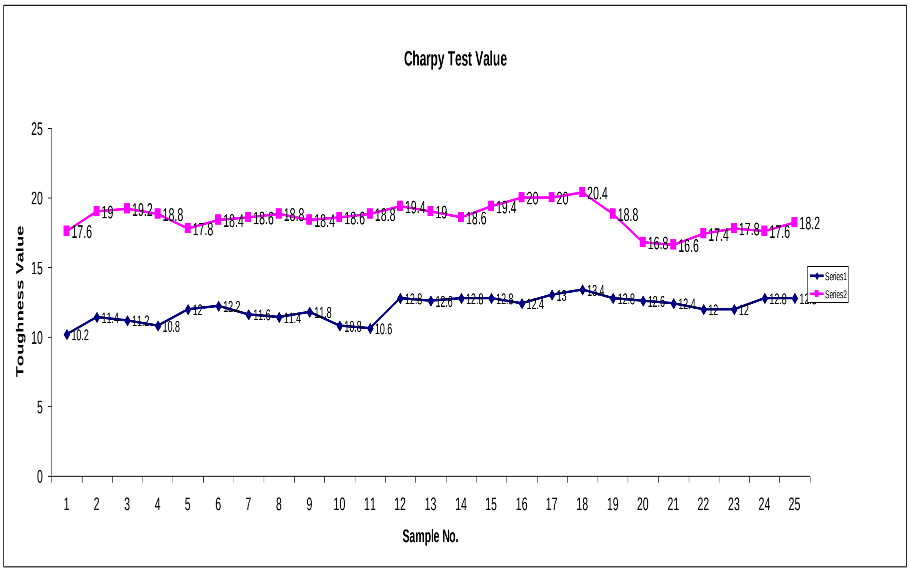
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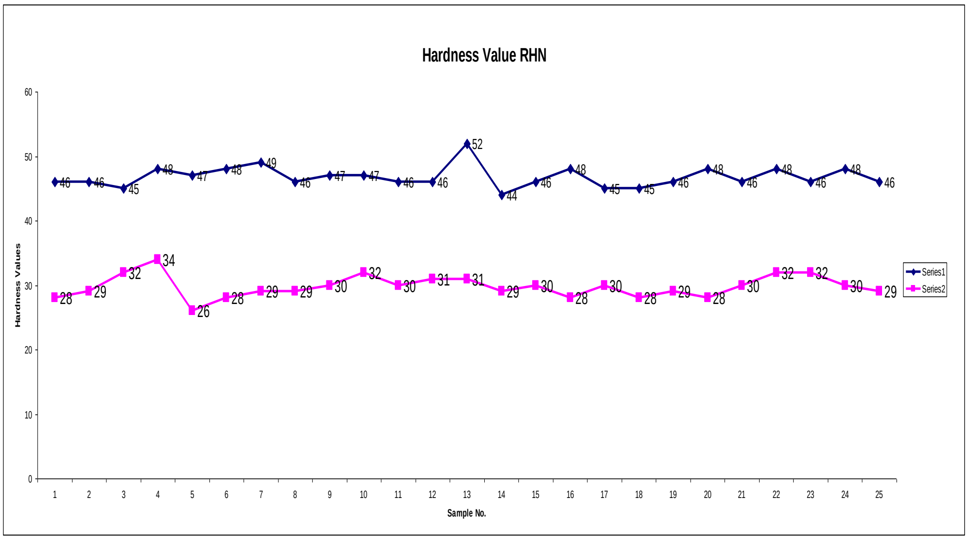
Series2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Hardness Values
Sample No.
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Series2