IMPROVING WELDING PRODUCTIVITY IN MMAW PROCESS USING TAGUCHI'S TECHNIQUES

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TO

THE HANDS OF

"WELD" WISHERS

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SYNOPSIS

Globalization of economics and the information technology (IT) high way made the entire planet into a global village. As the markets become competitive and customers become more knowledgeable, today's manufactures are under high pressure to maintain their company's competitive position in the market. Hence, they are forced to look for ways and means to maximize the productivity so that profit can be maximized.

This project deals with the ways of improving welding productivity and minimizing welding cost in a heavy fabrication industry through optimization of process parameters.

The main problem faced in the heavy fabrication industry by manual metal arc welding (MMAW) process is the selection of the optimum combination of input process control parameters for achieving the required quality of weld with improved production rate.

Studying the entire fabrication process right from joint design and selecting the most influencing process control parameters can solve the problem. The process parameters identified were welding current (I), welding sped (S), joint angle (A). These parameters were selected as input factors for the Taguchi technique to optimize them and their responses viz., consumption of electrode (Y_c) and weld strength (Y_s).

By selecting two levels, three factors orthogonal array, the experiments were conducted on 300x150 mm size mild steel plate of thickness 6mm and the main effect and interaction effect of parameters were studied. These experiments are useful in optimizing the process control parameters and improving welding productivity at a competitive welding cost.

CONTENTS

LITERATURE SURVEY

2.1. PRODUCTIVITY AND ITS IMPROVEMENT

Introduction

Productivity has now become an everyday watchworld. It is crucial to the welfare of industrial firm as for the economy progress of the country. High productivity refers to doing the work in a shortest possible time with least expenditure on inputs without sacrificing quality and with minimum wastage of resources.

Today the term productivity has acquired a wider meaning. Originally, it was used only to rate the workers according to skills. The persons who produced more either faster or harder were said to have higher productivity. Subsequently emphasis was laid to improve the hourly output by analyzing and improving upon the techniques applied by different workers. A system of measurement was then evolved to compare the improvement made in relation to the rate of output and in order to improve productivity further, machines were introduced. Manufacturers of machines started incorporating new features with the help of latest technological developments. Today we have machines that are completely controlled by computers. Computers have now become powerful tools towards improving productivity.

Concept

Productivity is the quantitative relation between what we produce and what we use as a resource to produce them, i.e., arithematic ratio of amount produced (output) to the amount of resources (input).

Productivity can be expressed as:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Productivity refers to the efficiency of the production system. It is the concept that guides the management of production system. It is an indicator of how well the factors of production (land, labour, material, energy) are utilized.

Definitions of Productivity

1. Productivity is a function of providing more and more of everything to more and more people with less and less consumption of resources.
2. The volume of output attained in a given period of time in relation to the sum of the direct and indirect efforts expended in its production.
3. Productivity is the measure of how well the resources are brought together in an organization and utilized for accomplishing a set of objectives.
4. Productivity is concerned with establishing congruency between organizational goals with societal aspirations through input-output relationship.
5. Produduitviy is the multiplier effect of efficiency and effectiveness.

Production and Productivity

Production is defined as a process or procedure to transform a set of input into output having the desired utility and quality. Production is a value added process. Production system is an organized process of conversion of raw materials into useful finished products represented as in figure 2.1

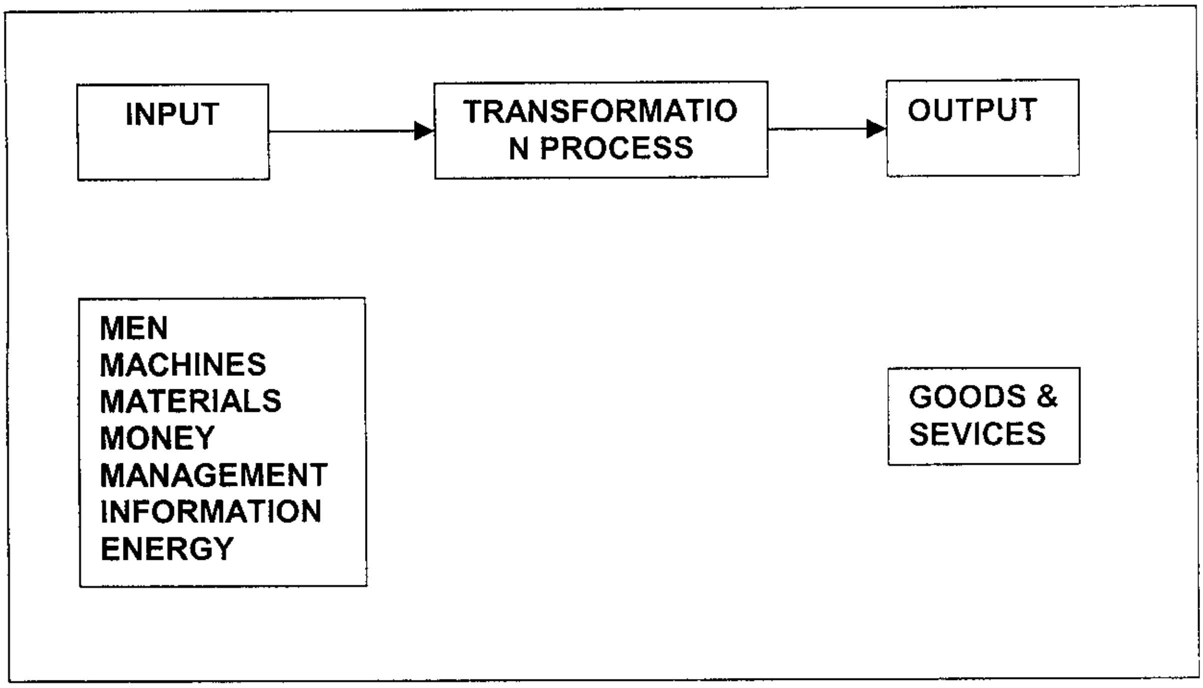


Figure 2.1 Production System

The concept of production and productivity are totally different. Production refers to output whereas productivity is a relative term where in the output is always expressed in terms of inputs. Increase in production may or may not be an indicator of increase in productivity. If the production is increased for the same output, the there is an increase in productivity.

Productivity can be increased

1. When production is increased without increase in inputs.
2. The same production with decrease in inputs.
3. The rate of increase in output is more compared to rate of increase in input.

Expectations from Productivity

Expectations differ among the various stakeholders, some of the expectations are quite contrast, i.e., the workers expect more leisure time in contrast to managers of hard work. Table 2.1 shows the expectations of various groups interested in productivity.

Table 2.1 Expectations from Productivity

Management and entrepreneurs	High return on investment, higher market share and corporate image
Managers	Maximum utilization of resources, lower unit cost, higher quality.
Workers	Higher wages, safer work environment, increased quality of life.
Suppliers	Prompt payment, continous order.
Customers	Lower cost, quality, reliability, safety, and timeness delivery.
Shareholders	Higher dividends

Benefits from Productivity

Always there is a misunderstanding about productivity in the mind of the workforce. To the workers, higher productivity means higher work, higher efforts, more profit to owners and unemployment. This is not the correct observation.

Productivity integrates the objectives of owners and workers. Productivity contributes towards increase in production through efficient utilization of resources and inputs rather than making workers to work hard. Productivity strives to minimize the human hazards and human efforts with a view to utilize them to those where they can contribute maximum to the output.

Dynamics of Productivity Change

Productivity improvement results in lower cost per unit by effective utilization of all the resources and reducing wastages. Lower cost per unit contributes to increased profit levels so that company can reinvest the surplus in new technology, equipment's and machines. This will result in further productivity increase and also there is a greater employment generation due to new investments. The productivity increase results in higher wages as profit potential of the company increases thereby increasing purchasing power of workers. The productivity increase sets in a chain reaction as shown in figure 2.2.

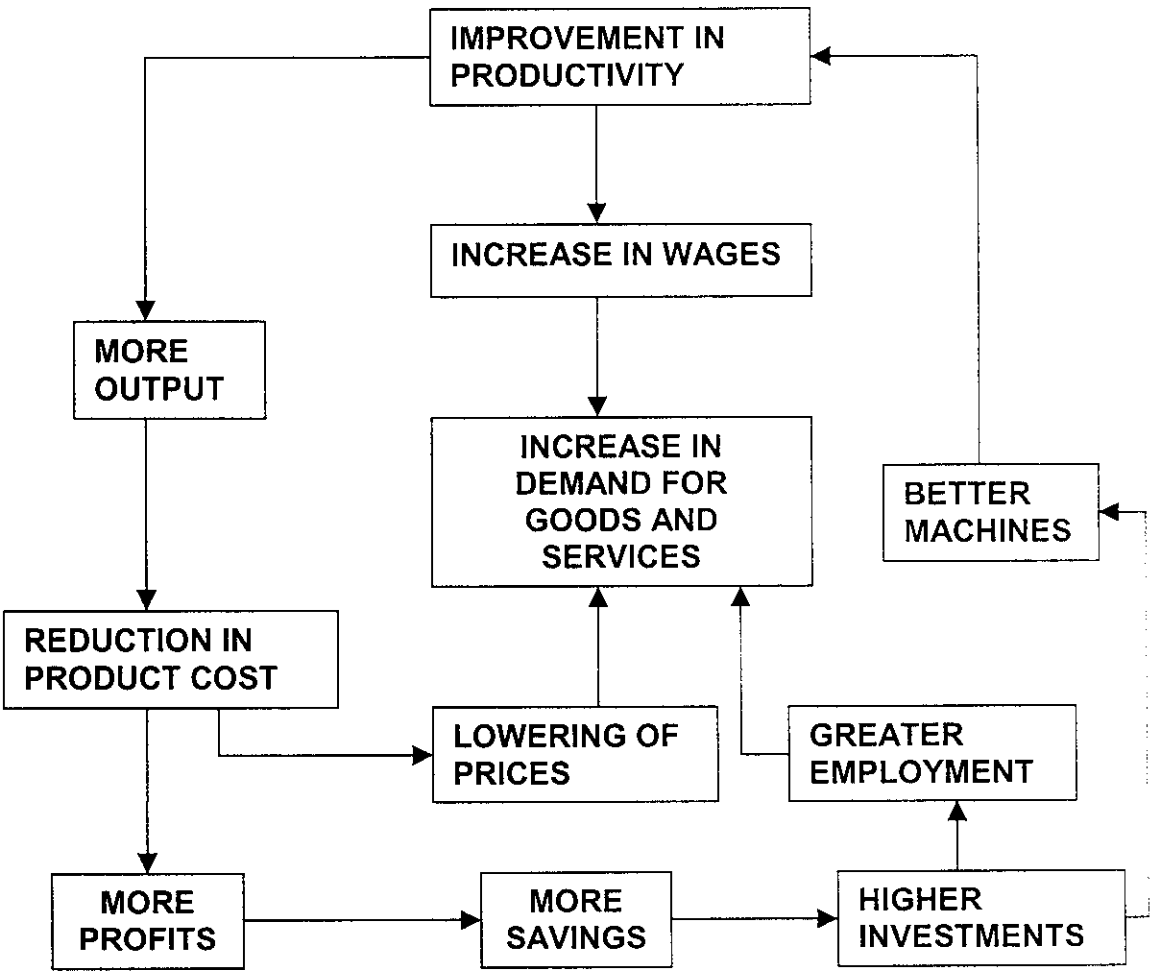


FIGURE 2.2 Dynamics of Productivity Change

Productivity Improvement Techniques

The basic productivity improvement techniques are represented in the figure 2.3

Technology Based

1. Computer Aided Design (CAD)
2. Computer Aided Manufacturing (CAM)
3. Computer Integrated Manufacturing Systems (CIMS)
4. Flexible Manufacturing System (FMS)
5. Robotics.
6. Laser technology.
7. Energy technology.

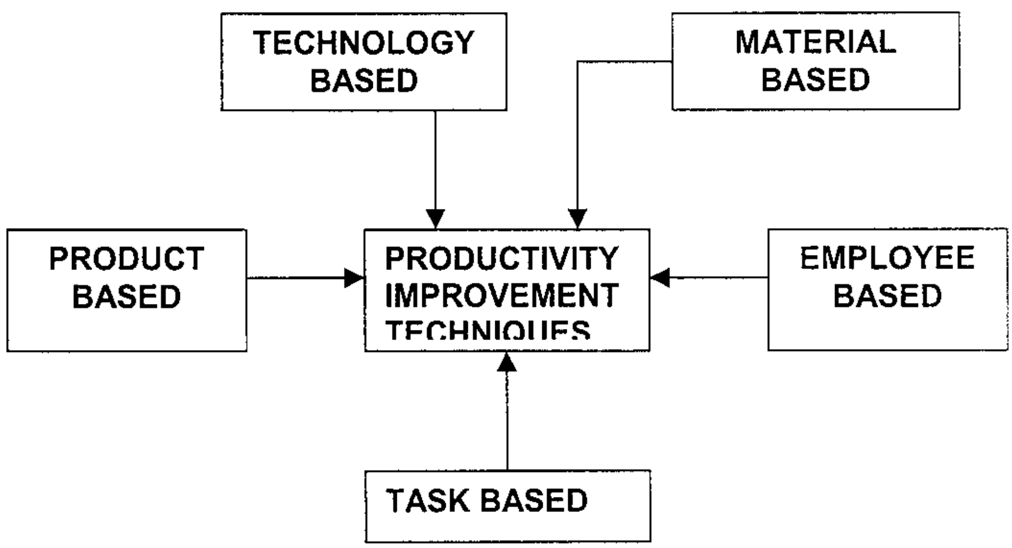


Figure 2.3 Productivity Improvement Techniques

Employee Based

1. Financial and non-financial incentives at individual and group level
2. Employee promotion
3. Job design, job enlargement, and job enrichment.
4. Worker participation in decision-making
5. Quality circles, small group activities.
6. Personnel development.

Material Based

1. Material planning and control.
2. Purchasing, logistics.
3. Material storage and retrieval.
4. Source selection and procurement of quality material.
5. Waste elimination.

Process Based

1. Methods engineering and works simplification.
2. Job design, job evoluation, and job safety.
3. Human factors engineering

Product Based

1. Value analysis and value Engineering.
2. Product diversification.
3. Standardization and simplification.
4. Reliability engineering
5. Product mix and promotion.

Management Based

1. Management style.
2. Communication in the organization.
3. Work culture.
4. Motivation.
5. Promoting group activity.

2.2. TAGUCHI'S QUALITY PHILOSOPHY

Definition of Quality

Genichi Taguchi has an unusual definition for quality:" quality is the loss a product causes to society after being shipped other than any losses caused by its intrinsic functions". By"loss" Taguchi refers to the following two categories:

1. Loss caused by variability of function.
2. Loss caused by harmful side effects.

Taguchi's quality system

Western books on quality frequently divide quality systems into two parts namely:

1. Quality of design
2. Quality of conformance.

Dr.Taguchi refers to these two parts as:

1. Off-line quality control
2. On-line quality control

Off-line Quality Control

It is concern with:

1. Correctly identifying the customer needs and expectations.

2. Designing a product which will meet customer expectations,
3. Designing a product, which can be consistently and economically manufactured,
4. Developing clear and adequate specifications, standards, procedures and equipment for manufacture.

On-line Quality Control

Taguchi identifies three forms of on-line quality control:

1. Process diagnosis
2. Prediction and correction
3. Measurement and correction

2.3. Design Optimization

Definition

[8] Optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function. Optimization is the act of obtaining best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is to either minimize the effort required or maximize the desired benefit.

Engineering Application of Optimization

Optimization, in its broadest sense, can be applied to solve any engineering problem. To indicate the wide scope of the subjevt, some typical application from different engineering disciplines are given below:

1. Finding the optimal trajectories of space vehicles.
2. Minimum weight design of structures for earthquake, wind and other types of random loading.
3. Design of water resource systems for maximum benefit.
4. Optimal plastic design of structures.
5. Optimum design of linkages, cams, gears, machine tools and other mechanical components.
6. Design of material handling equipment like conveyers, trucks and cranes for minimum cost.
7. Optimum design of electrical machinery like motors, generators and transformers.
8. Planning of maintenance and replacement of equipment to reduce operating costs.

3. PROBLEM DEFINITION

Introduction

Welding, like any other manufacturing operation, costs money. In general, the cost of welding is especially important when the cost itself is large or when it represents a significant proportion of the total cost of a project or contract or when expressed on an annual basis. Moreover, welding is directly related to other operations. In general fabrication, the single most important trade could be welding. Most of the other activities or operations can be considered as allied operations to the welding. It is possible to express the items listed as approximate percentage of the total cost of the production:

Materials	30%
Preparation	12%
Handling	6%
Welding	**30%**
Dressing	15%
Heat treatment	4%
Inspection	3%

Welding costs at 30% are obviously important and hence, the important of welding productivity.

We are today employing many welding processes like Manual Metal Arc Welding, Semi-Automatic and Automatic Submerged Arc welding, Co_2 Welding, TIG welding, Electro slag Welding etc. Among all these practices, manual metal Arc Welding is the one most widely employed.

It is estimated that in India, manual metal arc welding using coated stick electrodes accounted for more than 95 percent of the total weld metal deposited, while in advanced countries, the ratio did not exceed 70 to 80 percent. Even, ten years later, according to the report of the welding group of the National Committee on Science and Technology (NCST) this ratio would remain at 90%. Therefore, the traditional welding processes must be re-examined to determine how they can be utilized to achieve maximum productivity.

Industrial Chimney

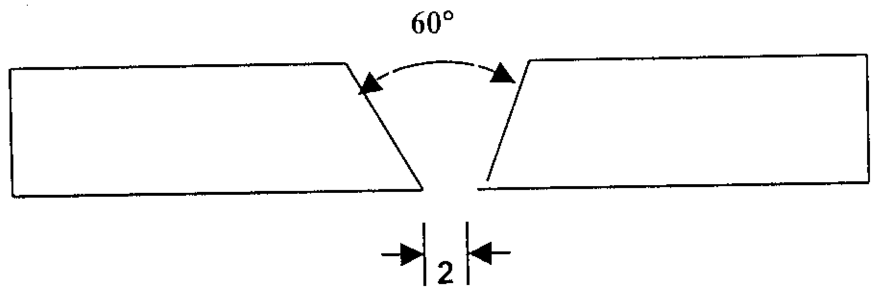
An industrial chimney fabrication has been taken for the study of productivity improvement. It made up of 6mm thick mild steel plate. It contains the following structural elements

1. Upper part
2. Middle part
3. Lower part

Joint Design

Most of the welds produced are usually over designed, if only by small amount. The welder in most of the instances adds by making a further contribution, again, by depositing slightly a greater amount of weld metal than intended by the designer. The accumulations of both contributions finish up with a weldment produced in a longer period of time at a higher cost.

Existing Joint Design



Total length to be welded

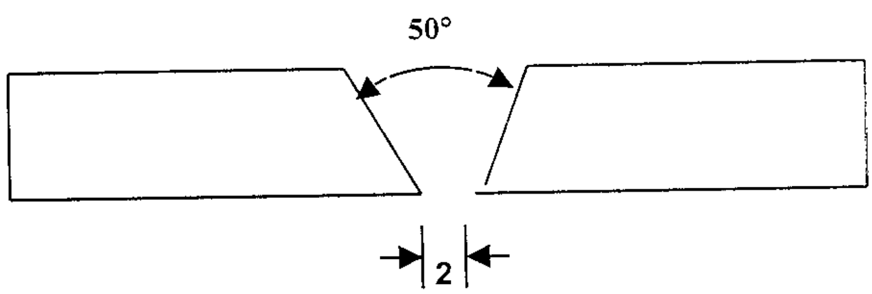
1) Lower part = 2.35+2.35+3 = 7.7m
2) Middle part = 1.88+0.6+2.4 = 4.88m
3) Upper part = 1.4+0.6+2.4 = 4.44m

Total = 17.02m

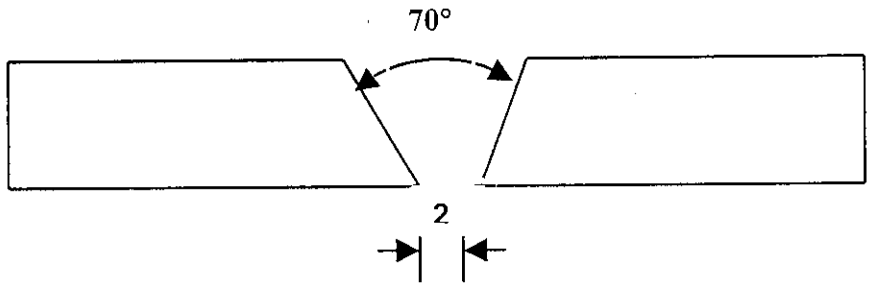
To achieve more meters of weld with lesser input as compared with the earlier process parameters, two types of joint design has been introduced, namely,

1. Open Single V-Groove Joint
2. Closed Single V-Groove Joint

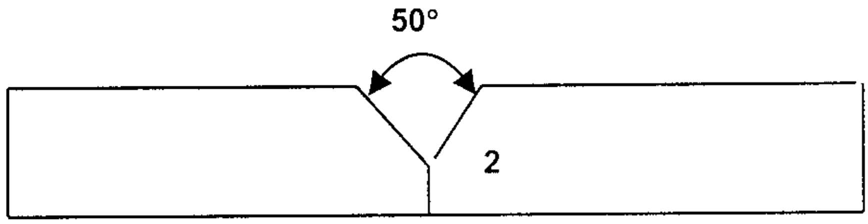
I (A). Open Single V-Groove with 50° Angle



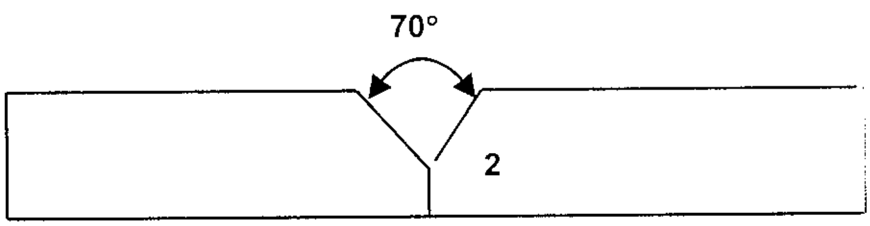
I (B). Open single v-Groove with 70° Angle



I I (A). Closed Single V-Groove with 50° Angle



I I (B). Closed Single V-Groove with 70° Angle



Existing Process Parameters

Welding Current (I) = 175 Amps

Welding Speed (S) = 6.1 m/min

Joint Angle (A) = 60°

Problem Definition

In the fabrication of industrial chimney, the above stated process parameters were used and the electrode consumption was recorded as 174 cm/m of weld. The present work deals the means for increased productivity in the manual metal arc welding process. The idea is to look into all the aspects including weld metal requirements, joint design, and other factors and optimize the parameters to produce more meters of welds in a given frame time, maintaining the cost without compromising on the quality (weld strength).

Objectives of the Project

1. Effective utilization of resources
2. Reducing the wastages
3. Quality weld at lower price
4. Optimizing the process control parameters

4.1. TAGUCHI TECHNIQUE OF OPTIMIZATION

The Taguchi's design of experiment technique is divided into three phases namely,

1. Planning Phase
2. Conducting Phase
3. Analysis Phase

Plan of investigation

The study was planned to be carried out in the following steps:

1. Identifying the important process control variables.
2. Finding the upper and lower limits of the control variable
3. Select the suitable orthogonal array
4. Conducting the experiments as per the orthogonal array
5. Recording the responses
6. Presenting the main effects and the significant interaction effects of the process parameters on the responses in graphical form
7. Conducting the conformation experiment

1. Identification of the Process Variables

The following independently controlled process parameters were identified to carry out the experiments:

1. Welding current (I)
2. Welding speed (S)
3. Joint angle (A)

2. Finding the Limits of the Control Variable

Trial runs were carried out by varying one of the process parameters whilst keeping the rest of them at constant values [3]. THE working range was decided upon by inspecting the bead for smooth appearance and the absence of any visible defects. The upper and lower limits of the factor was coded as - and +. The selected process parameters with their limits, units and notations are given in table 4.1

Table 4.1 Process Control Parameters and their Limits

Parameters	Units	Notation	Limits	
			-	+
Welding Current	Amps	I	125	150
Welding Speed	M/min	S	5.4	8.3
Joint Angle	Degrees	A	50	70

3. Select the Suitable Orthogonal Array

Orthogonal array is a table, which provides the combinations of parameters, and their levels with in which the experiment is to be conducted.

Number of process parameters: three namely,

1. Welding current (I)
2. Welding speed (S)
3. Joint angle (A)

Number of levels: two, namely,

1. Minimum level
2. Maximum level

Number of experiments to conducted is given by the formula = 2^k

Where,'k' is the number of parameters.

Therefore the number of experiments to conducted is $2^k = 2^3 = 8$

Table 4.2 Orthogonal Array

Experiment	Treatments			Observed Response
	I	S	A	
1	-	-	-	Y_1
2	+	-	-	Y_2
3	-	+	-	Y_3
4	+	+	-	Y_4
5	-	-	+	Y_5
6	+	-	+	Y_6
7	-	+	+	Y_7
8	+	+	+	Y_3

4. Conducting the Experiments as Per the Orthogonal Array

Experiments were conducted as per the orthogonal array at random to avoid the possibility of systematic error infiltrating the system. The weld was done on the mild steel plate of 300*150*6 mm size. The electrode used was ER4211 of diameter 3.15 mm (10gauge). Keeping positive polarity and an electrode to work angle of 70°.

5. Recording the Responses

Before going for welding the electrode length was measured in cm (X_1). Then the welding operation was carried out on the specimen plate. After welding has been over the length of electrode was measured (X_2). This length difference (X_1- X_2) gives the electrode consumption (Y_c) in cm/m of weld.

With the help of universal testing machine (UTM) of capacity 10000kgf the welding tensile strength (Y_s) was calculated by breaking the welded work specimen. The values obtained from the UTM are converted into N/mm^2.the observed responses are recorded in the table 4.3 and 4.4

Table 4.3 Recorded Response as per the Experiment Conducted.

1. Open Single V- Groove Joint

Experiment	Treatments			Y_c Cm/m	Y_s N/mm^2
	I	S	A		
1	-	-	-	144	344.98
2	+	-	-	194	316.37
3	-	+	-	208	310.65
4	+	+	-	138	355.61
5	-	-	+	172	332.72
6	+	-	+	230	319.64
7	-	+	+	244	354.79
8	+	+	+	182	316.37

Table 4.4 Recorded Response as per the Experiment Conducted.

1. Closed Single V- Groove Joint

Experiment	Treatments			Y_c	Y_s
	I	S	A	Cm/m	N/mm^2
1	-	-	-	126	255.87
2	+	-	-	176	296.75
3	-	+	-	186	298.38
4	+	+	-	122	327.00
5	-	-	+	150	326.00
6	+	-	+	210	327.81
7	-	+	+	224	261.60
8	+	+	+	134	301.65

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE
(By Considering Main Effect of Parameters on Response for Electrode Consumption)

The observed responses are transformed into “Response Table”. The values of the responses are plotted by performing procedures given in the response table – 4.5

Table 4.5 Responses Table for a Three Factor Two Level Experiment

Random Number	Trail	Observed Response	A		B		C	
			1	2	1	2	1	2
6	1	Y1		*		*		*
5	2	Y2		*		*	*	
4	3	Y3		*	*			*
2	4	Y4		*	*		*	
3	5	Y5	*			*		*
7	6	Y6	*			*	*	
1	7	Y7	*		*			*
8	8	Y8	*		*		*	
Total		**SUM OF OBSERVATION IN COLUMNS**						
No. Of data Value		8	4	4	4	4	4	4
Average		Y BAR	$Abar_1$	$Abar_2$	$Bbar_1$	$Bbar_2$	$Cbar_1$	$Cbar_2$
Est. Main Effect			$Abar_1$-1 $Abar_2$		$Bbar_1$. $Bbar_2$		$Cbar_1$. $Cbar_2$	

A. Response Table Along With Main Effect (For Electrode Consumption in cm/m of Weld)

Table 4.6

Random Number	Trail	Observed Response Y_c	I		S		A	
			1	2	1	2	1	2
6	1	230	230	*	230	*	230	*
5	2	172	172	*	172	*	*	172
4	3	138	138	*	*	138	138	*
2	4	194	194	*	*	194	*	194
3	5	208	*	208	208	*	208	*
7	6	244	*	244	244	*	*	244
1	7	144	*	144	*	144	144	*
8	8	182	*	182	*	182	*	182
Total		1512	734	778	854	658	720	792
No. of data value		8	4	4	4	4	4	4
Average		189	183.50	194.50	213.50	164.50	180.00	198
Est. main effect			11		49		18	

I. Optimization of Response for Open Single V- Groove Joint

A. Electrode Consumption

Optimized response (Yc) Y bar_{min} = Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

Where,

Y bar_{min}	-	Optimized Response for Electrode Consumption
Ybar	-	Average of All Response for Electrode Consumption
I_1bar	-	Average of Response Corresponding to I_1
S_1bar	-	Average of Response Corresponding to S_1
A_1bar	-	Average of Response Corresponding to A_1

Ybar = 189, I_1bar = 183.50, S_1bar = 164.50, A_1bar = 180.00

Optimized response (Yc) Y bar_{min}= Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

= 189+ (183.5-189) + (164.5-189) + (180-189)

= 150 cm/m of weld

A. Response Graph Along With Main Effect (For Electrode Consumption in cm/m of Weld)

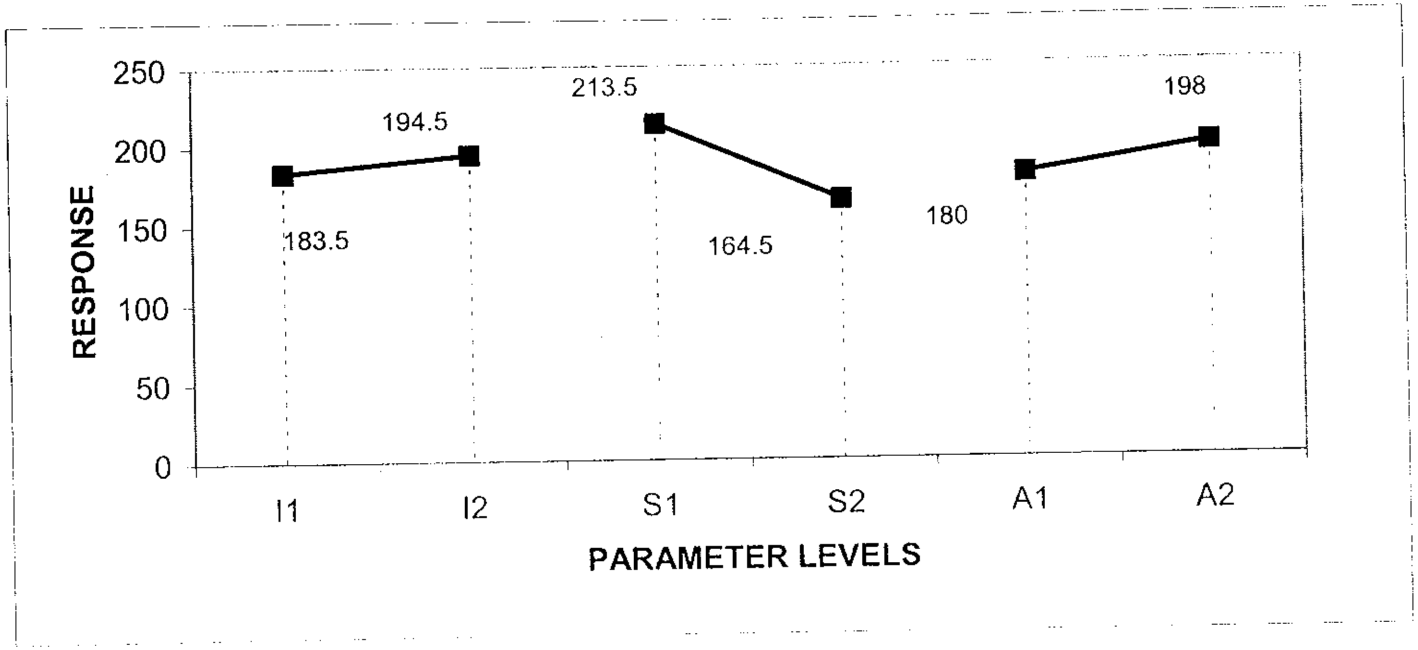


Figure 4.1

Optimization of Parameters

From the table-4.6 the estimated main effect of parameters on response is plotted in terms of graphical form as shown in the figure 4.1

1) Estimated main effect of "I" on response = 11 cm/m
2) Estimated main effect of "S" on response = 49 cm/m
3) Estimated main effect of "A" on response = 18 cm/m

To optimize the parameters a dotted line is drawn in the figure 4.1 from the response graphs I, S and A, and such that, the value (or) point closer to the optimized value of 150cm/m of weld, is taken so from the graph, it was found that, the dotted line meets at I_1, S_1 and A_1 coordinate on the X axis.

Hence, the optimized response is given by,

1) Welding current = 125 Amps
2) Welding speed = 8.3m/min
3) Joint angle = 50°

I. Open Single V- Groove Joint

B.Response Table Along With Main Effect (For Weld Strength in N/mm^2)

TABLE 4.7

Random Number	Trail	Observed Response Y_S	I		S		A	
			1	2	1	2	1	2
6	1	319.64	319.64	*	319.64	*	319.64	*
5	2	332.72	332.72	*	332.72	*	*	332.72
4	3	355.61	355.61	*	*	355.61	355.61	*
2	4	316.37	316.37	*	*	316.37	*	316.37
3	5	310.65	*	310.65	310.65	*	310.65	*
7	6	354.79	*	354.79	354.79	*	*	354.79
1	7	344.96	*	344.96	*	344.96	344.96	*
8	8	316.37	*	316.37	*	316.37	*	316.37
Total		2651.11	1323.34	1326.77	1317.80	1333.31	1330.86	1320.25
No. of Data value		8	4	4	4	4	4	4
Average		331.38	331.08	331.69	329.45	333.32	332.71	330.06
Est. main effect			0.61		3.87		2.65	

I. Optimization of response for Open Single V- Groove Joint

B. Weld Strength

Optimized response (Ys) $Y\ bar_{min}$ = $Ybar + (I_1bar - Ybar) + (S_1bar - Ybar) + (A_1bar - Ybar)$

Where,

$Y\ bar_{min}$ - Optimized Response for Weld Strength

Ybar - Average of All Response for Weld Strength

I_1bar - Average of Response Corresponding to I_1

I. Open Single V- Groove Joint

B.Response Graph Along With Main Effect (For Weld Strength in N/mm^2)

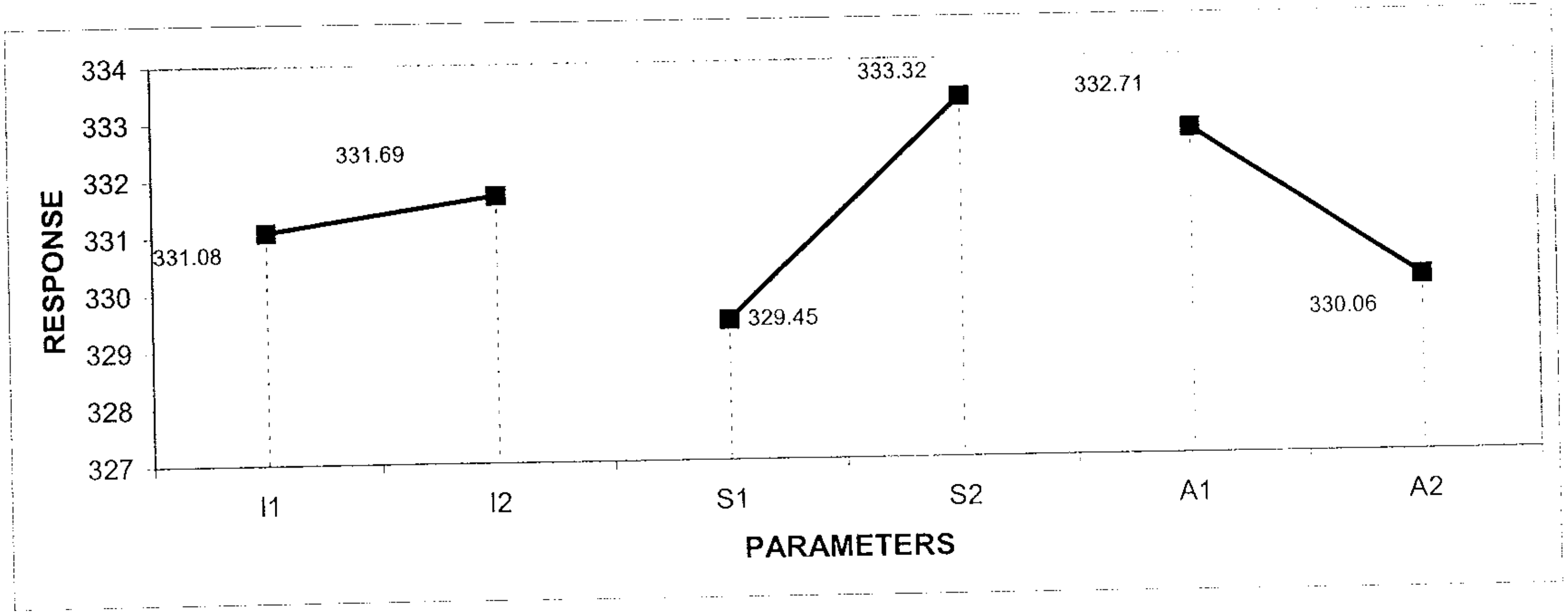


Figure 4.2

S_1bar - Average of Response Corresponding to S_1

A_1bar - Average of Response Corresponding to A_1

Ybar = 331.38, I_1bar = 331.69, S_1bar = 333.32, A_1bar = 332.71

Optimized response (Y_s) Y bar_{min} = Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

= 331.38+ (331.69-331.38) + (333.32-331.38) + (332.71-331.38)

= 334.96

Optimization of Parameters

From the table 4.7 the estimated main effect of parameters on response is plotted in terms of graphical form as shown in the figure 4.2

4) Estimated main effect of "I" on response = 0.61 N/mm^2
5) Estimated main effect of "S" on response = 3.897 N/mm^2
6) Estimated main effect of "A" on response = 2.65 N/mm^2

To optimize the parameters a dotted line is drawn in the figure 4.2 from the response graphs I, S and A, and such that, the value (or) point closer to the optimized value of 334.96N/mm^2, is taken so from the graph, it was found that, the dotted line meets at I_1, S_1 and A_2 coordinate on the X axis.

Hence, the optimized response is given by,

1) Welding current (I) = 150 Amps
2) Welding speed (S) = 8.3m/min
3) Joint angle (A) = 70°

II. Closed Single V- Groove Joint

A. Response Table Along With Main Effect (For Electrode Consumption in cm/m of Weld)

Table 4.8

Random Number	Trail	Observed Response Y_c	I		S		A	
			1	2	1	2	1	2
6	1	126	126	*	126	*	126	*
5	2	176	176	*	176	*	*	176
4	3	186	186	*	*	186	186	*
2	4	122	122	*	*	122	*	122
3	5	150	*	150	150	*	150	*
7	6	210	*	210	210	*	*	210
1	7	224	*	224	*	224	224	*
8	8	134	*	134	*	134	*	134
Total		1328	610	718	662	666	686	642
No. of data value		8	4	4	4	4	4	4
Average		166	152.5	179.5	165.5	166.5	171.5	160.5
Est. main effect			27		1		11	

I. Optimization of Response for Closed Single V- Groove Joint

A. Electrode Consumption

Optimized response (Yc) $Y\ bar_{min}$ = Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

Where,

$Y\ bar_{min}$	-	Optimized Response for Electrode Consumption
Ybar	-	Average of All Response for Electrode Consumption
I_1bar	-	Average of Response Corresponding to I_1

II. Closed Single V- Groove Joint

A. Response Graph Along With Main Effect (For Electrode Consumption in cm/m of Weld)

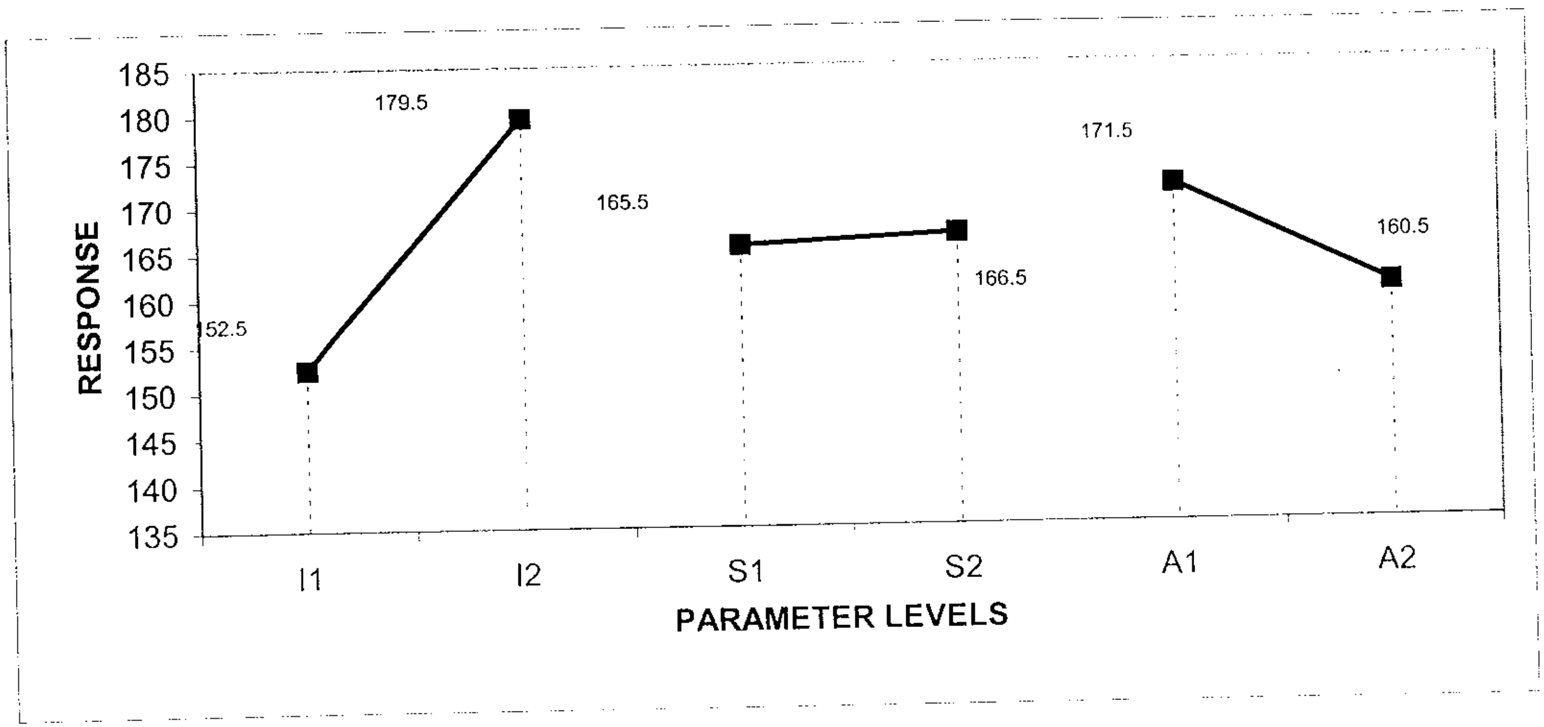


Figure 4.3

S_1bar - Average of Response Corresponding to S_1

A_1bar - Average of Response Corresponding to A_1

Ybar =166, I_1bar =152.50, S_1bar =165.50, A_1bar = 160.50

Optimized response (Yc) Y bar_{min}= Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

= 166+ (152.50-166) + (165.5-166) + (160.50- 166)

Y bar_{min} = 146.5 cm/m of weld

Optimization of Parameters

From the table 4.8 the estimated main effect of parameters on response is plotted in terms of graphical form as shown in the figure 4.3

1) Estimated main effect of "I" on response = 27 cm/m
2) Estimated main effect of "S" on response = 1 cm/m
3) Estimated main effect of "A" on response = 11 cm/m

To optimize the parameters a dotted line is drawn in the figure 4.8 from the response graphs I, S and A, and such that, the value (or) point closer to the optimized value of 146.5 cm/m of weld, is taken so from the graph, it was found that, the dotted line meets at I_1, S_1 and A_2 coordinate on the X axis.

Hence, the optimized response is given by,

1) Welding current = 125 Amps
2) Welding speed = 5.3m/min
3) Joint angle = 70°

II. Closed Single V- Groove Joint

B.Response Table Along With Main Effect (For Weld Strength in N/mm^2)

Table 4.9

Random Number	Trail	Observed Response Y_S	I		S		A	
			1	2	1	2	1	2
6	1	255.87	255.87	*	255.87	*	255.87	*
5	2	296.75	296.75	*	296.75	*	*	296.75
4	3	298.38	298.38	*	*	298.38	298.38	*
2	4	327.00	327.00	*	*	327.00	*	327.00
3	5	326.00	*	326.00	326.00	*	326.00	*
7	6	327.81	*	327.81	327.81	*	*	327.81
1	7	261.60	*	261.60	*	261.60	261.60	*
8	8	301.65	*	301.65	*	301.65	*	301.65
Total		2395.06	1178	1217.06	1206.43	1188.63	1141.85	1253.21
No. of Data value		8	4	4	4	4	4	4
Average		299.38	294.50	304.26	301.60	297.15	285.46	313.30
Est. main effect			9.76		4.45		27.84	

II. Optimization of Response for Closed Single V- Groove Joint

B. Weld Strength

Optimized response (Ys) Y bar_{min} = Ybar + (I_1bar – Ybar) + (S_1bar – Ybar) + (A_1bar – Ybar)

Where,

Y bar_{min} - Optimized Response for Weld Strength

Ybar - Average of All Response for Weld Strength

I_1bar - Average of Response Corresponding to I_1

S_1bar - Average of Response Corresponding to S_1

II. Closed Single V- Groove Joint

B.Response Graph Along With Main Effect (For Weld Strength in N/mm^2)

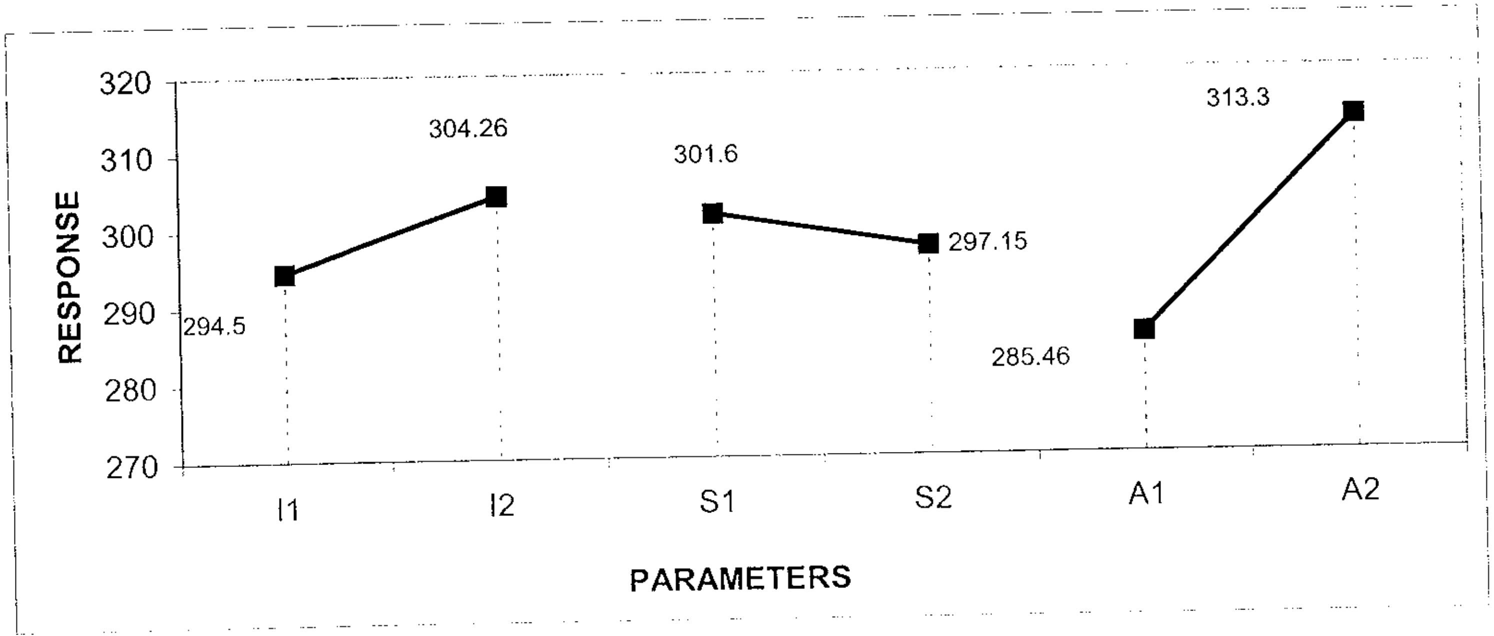


Figure 4.4

A_1bar - Average of Response Corresponding to A_1

$Ybar = 299.38$, $I_1bar = 304.26$, $S_1bar = 301.60$, $A_1bar = 313.30$

Optimized response (Ys) $Y\,bar_{min} = Ybar + (I_1bar - Ybar) + (S_1bar - Ybar) + (A_1bar - Ybar)$

$= 299.38 + (304.26 - 299.38) + (301.60 - 299.38) + (313.30 - 299.38)$

= 320.40 N/mm2

Optimization of Parameters

From the table 4.9 the estimated main effect of parameters on response is plotted in terms of graphical form as shown in the figure4.4

1) Estimated main effect of "I" on response = 9.76 N/mm^2
2) Estimated main effect of "S" on response = 4.45 N/mm^2
3) Estimated main effect of "A" on response = 27.84 N/mm^2

To optimize the parameters a dotted line is drawn in the figure4.4 from the response graphs I, S and A, and such that, the value (or) point closer to the optimized value of 334.96N/mm^2, is taken so from the graph, it was found that, the dotted line meets at I_1, S_1 and A_1 coordinate on the X axis.

Hence, the optimized response is given by,

1) Welding current (I) = 150 Amps
2) Welding speed (S) = 5.3m/min
3) Joint angle (A) = 70°

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE (By Considering Interaction Effect of Parameters on Response)

The observed responses are recorded in the table 4.10 – 4.13.the objective function is taken as minimization for electrode consumption, and maximization for weld strength.

Optimization is a continuous process, it can be done further and further as per the optimization is concern, and considering interaction effect of parameter on response does provide better optimization than considering only main effect of parameters on the response. In connection with the above, the "Response Table" three more column is added to take into consideration of interaction of IS, IA, SA.

The same observed responses are entered in the modified response table and the estimated main effect and estimated interaction are found out for the response of Open Single V – Groove Joint. The modified response table for including the interaction is shown in figure 4.9 from the table, the estimated interaction of parameters of IS, IA, SA is as follows,

1) Estimated interaction effect of IS = 14 cm/m
2) Estimated interaction effect of IA = 19 cm/m
3) Estimated interaction effect of SA = 29 cm/m

The above values are plotted in terms of graphical form is shown in figures 4.5, 4.6, and 4.7. From the figure it was found that," IS" combination having more impact on the response than other combination of SA and IA.

Based on the figure 4.5,"IS" combination can be selected for further optimization. But it is necessary to know, whether there is an interaction effect among those parameters of "I "and "S" itself.

Similarly to know, interaction among IA, SA a method followed called "Average Response Table Method" in which an average responses are obtained at different combination of those parameters are shown in table 4.14 – 4.25.

Based on the average response tables, the interaction graphs are separately for IS, SA, IA as shown in figure 4.5 – 4.16."By referring the figures it was found that most of the combinations having a strong interaction between them" is explained by a rule as follows:

1) When the two lines of graphs parallel with each other represents there is no interaction among those parameters.

2) When two lines of graphs "Non parallel or interact with each other"represents there is strong interaction among those parameters.

I. Open Single V- Groove Joint

A. Response Table Along With Interaction Effect (For Electrode Consumption in cm/m of weld)

Table 4.10

Random Number	Trail	Observed Response Y_c	I		S		A		IS		IA		SA	
			1	2	1	2	1	2	1	2	1	2	1	2
6	1	230	230	*	230	*	230	*	*	230	*	230	*	230
5	2	172	172	*	172	*	*	172	*	172	172	*	172	*
4	3	138	138	*	*	138	138	*	138	*	*	138	138	*
2	4	194	194	*	*	194	*	194	194	*	194	*	*	194
3	5	208	*	208	208	*	208	*	208	*	208	*	*	208
7	6	244	*	244	244	*	*	244	244	*	*	244	244	*
1	7	144	*	144	*	144	144	*	*	144	144	*	144	*
8	8	182	*	182	*	182	*	182	*	182	*	182	*	182
Total		1512	778	734	854	658	720	792	784	728	718	794	698	812
No. of Data Value		8	4	4	4	4	4	4	4	4	4	4	4	4
Average		189	194.50	183.50	231.5	164.5	180	198	196	182	179.5	198.5	174.5	203.50
Est. Main Effect			11		49		18		14		19		29	

I. Open Single V- Groove Joint

B. Response table along with Interaction effect (For weld Strength in N/mm^2)

Table4.11

Random Number	Trail	Observed Response Ys	I		S		A		IS		IA		SA	
			1	2	1	2	1	2	1	2	1	2	1	2
6	1	319.64	319.64	*	319.64	*	319.64	*	*	319.64	*	319.64	*	319.64
5	2	332.72	332.72	*	332.72	*	*	332.72	*	332.72	332.72	*	332.72	*
4	3	355.61	355.61	*	*	355.61	355.61	*	355.61	*	*	355.61	355.61	*
2	4	316.37	316.37	*	*	316.37	*	316.37	316.37	*	316.37	*	*	316.37
3	5	310.65	*	310.65	310.65	*	310.65	*	310.65	*	310.65	*	*	310.65
7	6	354.79	*	354.79	354.79	*	*	354.79	354.79	*	*	354.79	354.79	*
1	7	344.96	*	344.96	*	344.96	344.96	*	*	344.96	344.96	*	344.96	*
8	8	316.37	*	316.37	*	316.37	*	316.37	*	316.37	*	316.37	*	316.37
Total		265.71	1324.34	1326.77	1317.80	1333.31	1330.86	1320.25	1337.42	1313.69	1304.7	1346.41	1388.08	1263.03
No. of Data Value		8	4	4	4	4	4	4	4	4	4	4	4	4
Average		331.38	331.08	331.69	329.45	333.32	332.71	330.06	334.35	328.42	326.17	336.60	347.02	315.75
Est. Main Effect			0.61		3.87		2.65		5.93		10.43		31.27	

II. Closed Single V- Groove Joint

A. Response table along with Interaction effect (For Electrode Consumption in cm/m of Weld)

Table 4.12

Random Number	Trail	Observed Response Y_c	I		S		A		IS		IA		SA	
			1	2	1	2	1	2	1	2	1	2	1	2
6	1	126	126	*	126	*	126	*	*	126	*	126	*	126
5	2	176	176	*	176	*	*	176	*	176	176	*	176	*
4	3	186	186	*	*	186	186	*	186	*	*	186	186	*
2	4	122	122	*	*	122	*	122	122	*	122	*	*	122
3	5	150	*	150	150	*	150	*	150	*	150	*	*	150
7	6	210	*	210	210	*	*	210	210	*	*	210	210	*
1	7	224	*	224	*	224	224	*	*	224	224	*	224	*
8	8	134	*	134	*	134	*	134	*	134	*	134	*	134
Total		1328	610	718	662	666	686	642	668	660	672	746	796	532
No. of Data Value		8	4	4	4	4	4	4	4	4	4	4	4	4
Average		166	152.50	179.50	165.5	166.5	171.50	160.50	167	165	168	186.5	199	133
Est. Main Effect			27		1		11		2		18.5		66	

II.Closed Single V- Groove Joint

B. Response Table Along with Interaction Effect (For Weld Strength in N/mm²)

Table 4.13

Random Number	Trail	Observed Response Ys	I		S		A		IS		IA		SA	
			1	2	1	2	1	2	1	2	1	2	1	2
6	1	255.87	255.87	*	255.87	*	255.87	*	*	255.87	*	255.87	*	255.87
5	2	296.75	296.75	*	296.75	*	*	296.75	*	296.75	296.75	*	296.75	*
4	3	298.38	298.38	*	*	298.38	298.38	*	298.38	*	*	298.38	298.38	*
2	4	327.00	327.00	*	*	327.00	*	327.00	327.00	*	327.00	*	*	327.00
3	5	326.00	*	326.00	326.00	*	326.00	*	326.00	*	326.00	*	*	326.00
7	6	327.81	*	327.81	327.81	*	*	327.81	327.81	*	*	327.81	327.81	*
1	7	261.60	*	261.60	*	261.60	261.60	*	*	261.60	261.60	*	261.60	*
8	8	301.65	*	301.65	*	301.65	*	301.65	*	301.65	*	301.65	*	301.65
Total		2395.06	1178	1217.06	1206.43	1188.63	1141.85	1253.21	1279.19	1115.87	1211.35	1183.71	1184.54	1210.52
No. Of Data Value		8	4	4	4	4	4	4	4	4	4	4	4	4
Average		299.38	294.50	304.26	301.60	297.15	285.46	313.30	319.79	278.96	302.83	295.92	296.13	302.63
Est. Main Effect			9.76		4.45		27.84		40.83		6.91		6.5	

Average Response Table – Interaction Effect of Parameters

I. (A) Opened Single v – Groove Joint (Electrode Consumption in cm/m)

IS Interaction

Table 4.14

Levels For Factors		Observed Response	Average Response
I	S		
1	1	144+172	158
1	2	208+244	226
2	1	194+230	212
2	2	138+182	160

IA Interaction

Table 4.15

Levels For Factors		Observed Response	Average Response
I	A		
1	1	144+208	176
1	2	172+244	208
2	1	138+194	166
2	2	230+182	206

SA Interaction

Table 4.16

Levels For Factors		Observed Response	Average Response
S	A		
1	1	144+194	169
1	2	172+230	201
2	1	208+138	173
2	2	244+182	213

Average Response Graph – Interaction Effect of Parameters
I. (A) Opened Single v – Groove Joint (Electrode Consumption in cm/m)

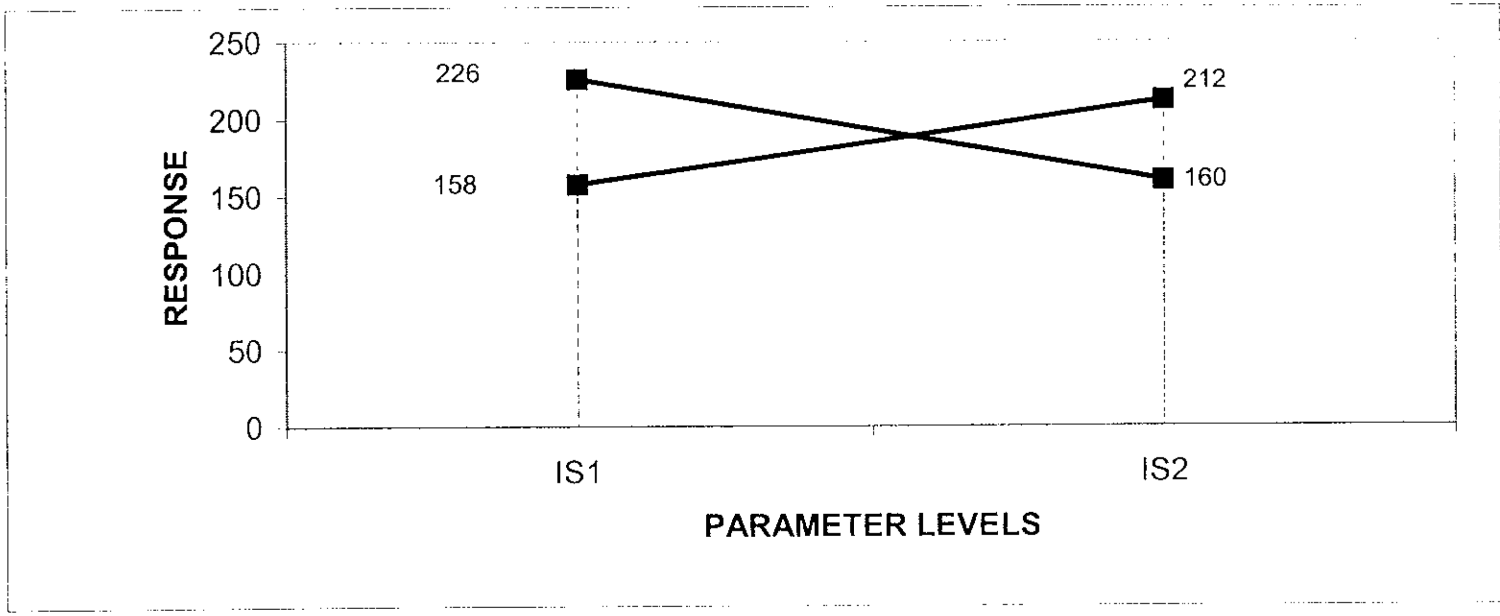


Figure 4.5 IS Interaction

Average Response Graph – Interaction Effect of Parameters
I. (A) Opened Single v – Groove Joint (Electrode Consumption in cm/m)

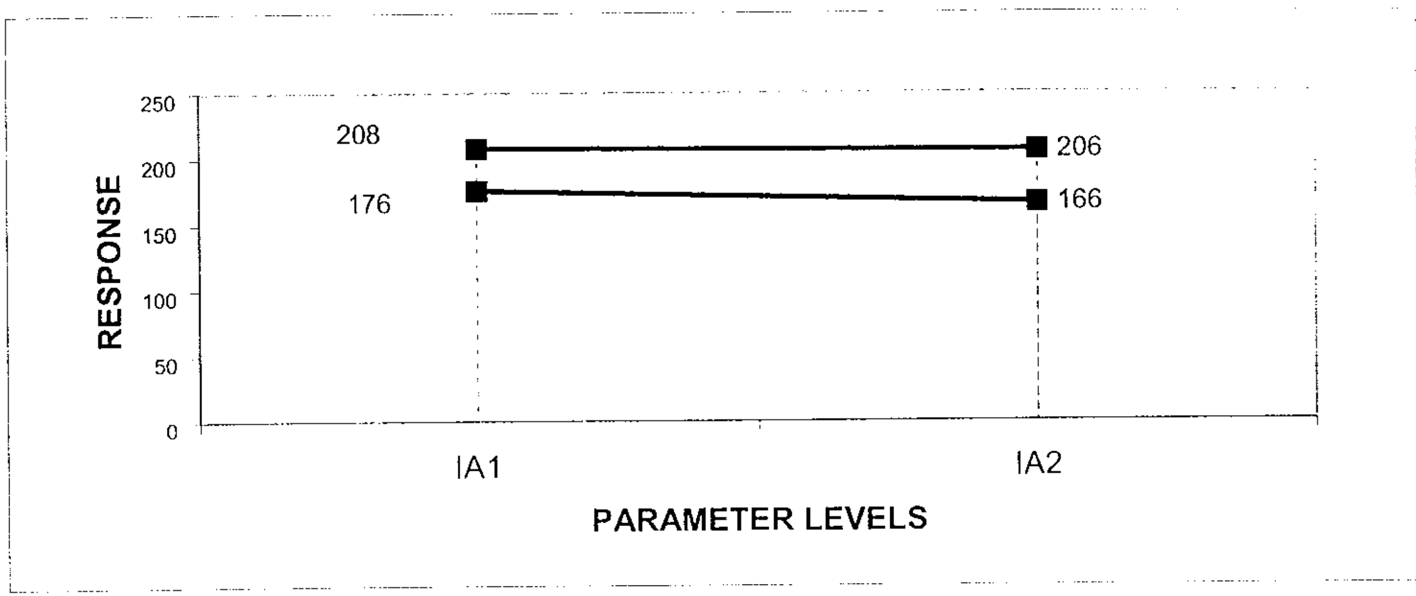


Figure 4.6 IA Interaction

Average Response Graph – Interaction Effect of Parameters
I. (A) Opened Single v – Groove Joint (Electrode Consumption in cm/m)

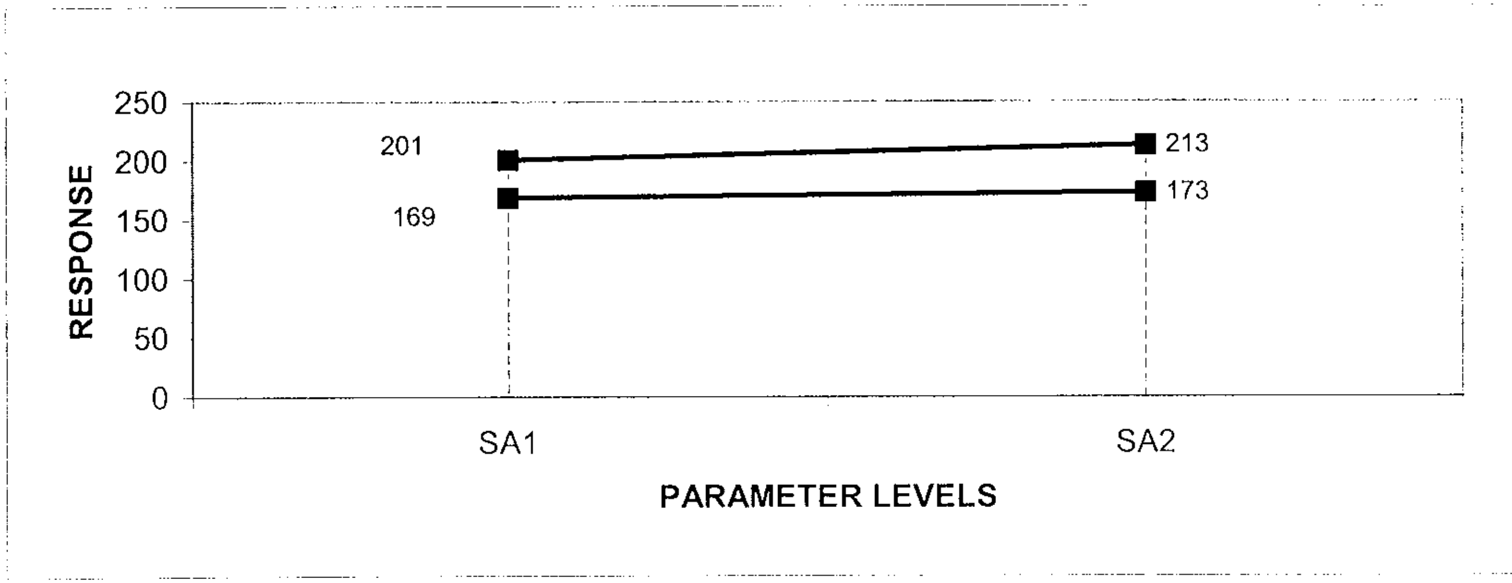


Figure 4.7 SA Interaction

Average Response Table – Interaction Effect of Parameters

I. (B) Opened single V – Groove Joint (Weld strength in N/mm^2)

IS Interaction

Table 4.17

Levels For Factors		Observed Response	Average Response
I	S		
1	1	344.98+332.72	338.85
1	2	310.65+354.79	332.72
2	1	316.37+319.64	318.00
2	2	355.61+316.37	335.99

IA Interaction

Table 4.18

Levels For Factors		Observed Response	Average Response
I	A		
1	1	344.98+310.65	327.81
1	2	332.72+354.79	343.75
2	1	316.37+355.61	335.99
2	2	319.64+316.37	318.00

SA Interaction

Table 4.19

Levels For Factors		Observed Response	Average Response
S	A		
1	1	344.98+316.37	330.675
1	2	332.72+319.64	326.18
2	1	310.65+355.61	333.13
2	2	354.79+316.37	335.58

Average Response Graph – Interaction Effect of Parameters

I. (B) Opened single V – Groove Joint (Weld strength in N/mm^2)

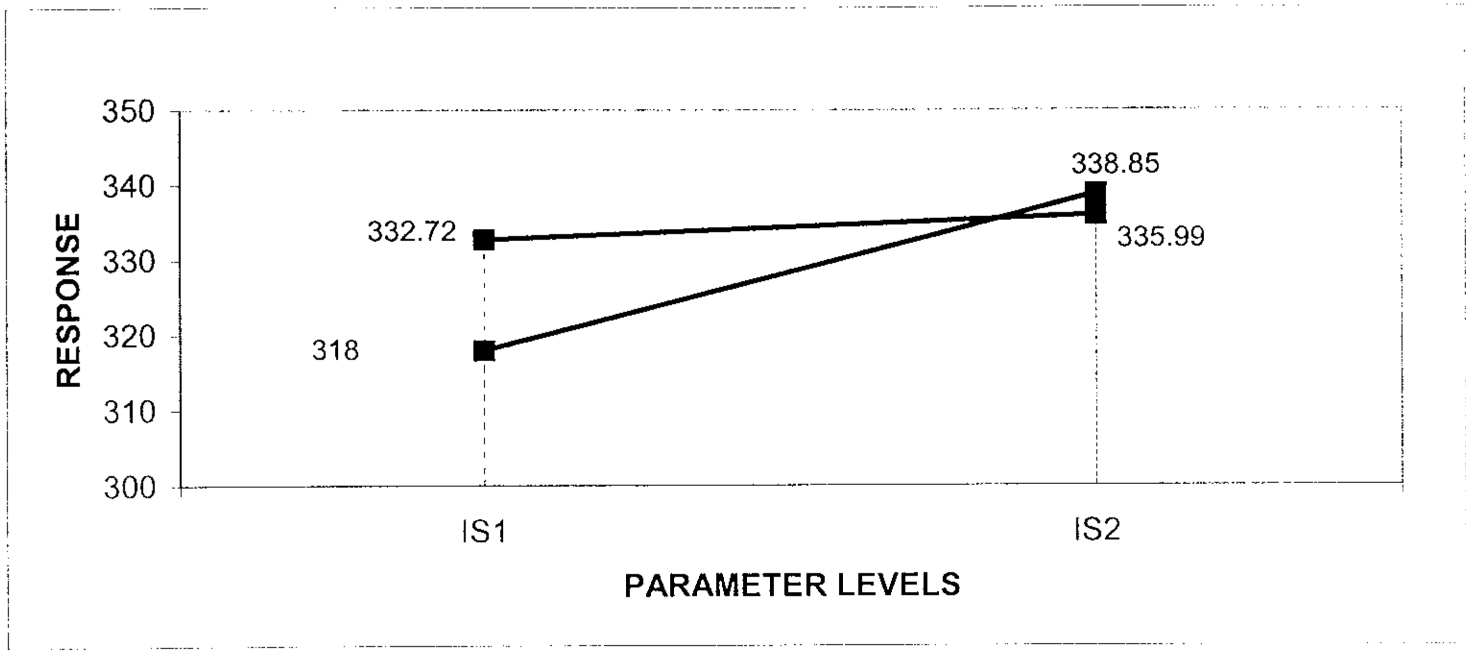


Figure 4.8 IS Interaction

Average Response Graph – Interaction Effect of Parameters

I. (B) Opened single V – Groove Joint (Weld strength in N/mm^2)

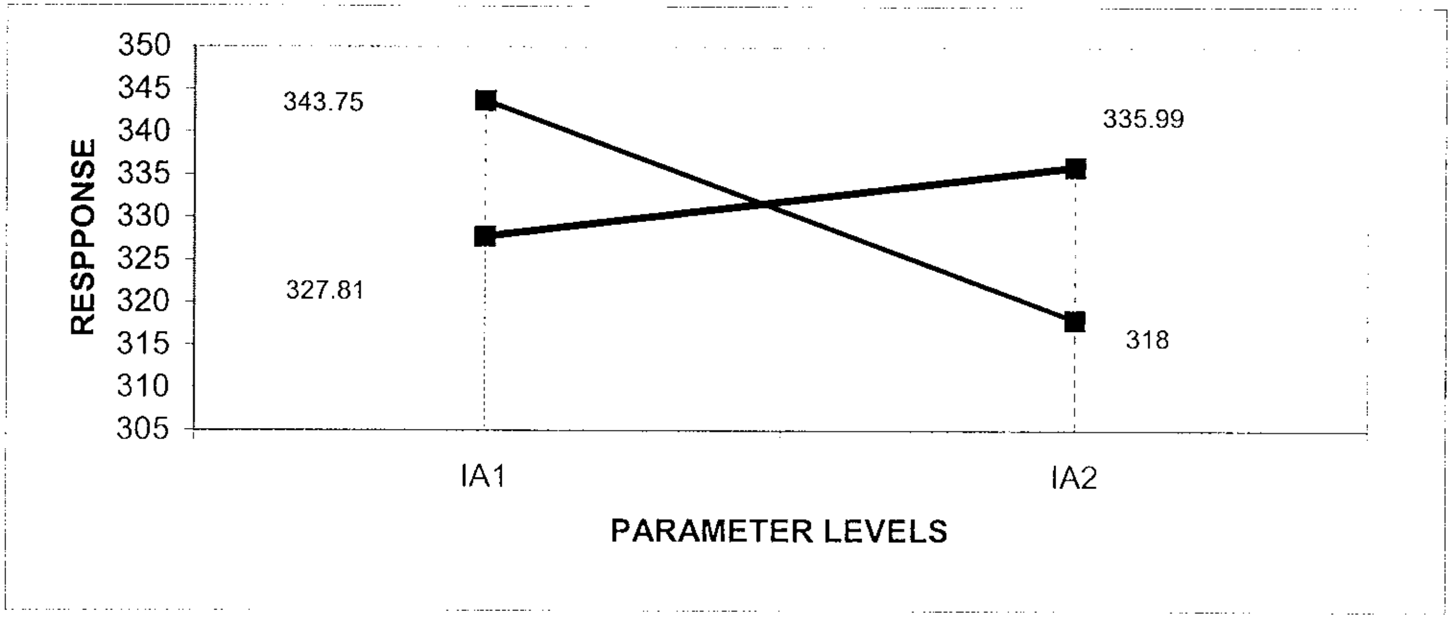


Figure 4.9 IA Interaction

Average Response Graph – Interaction Effect of Parameters

I. (B) Opened single V – Groove Joint (Weld strength in N/mm^2)

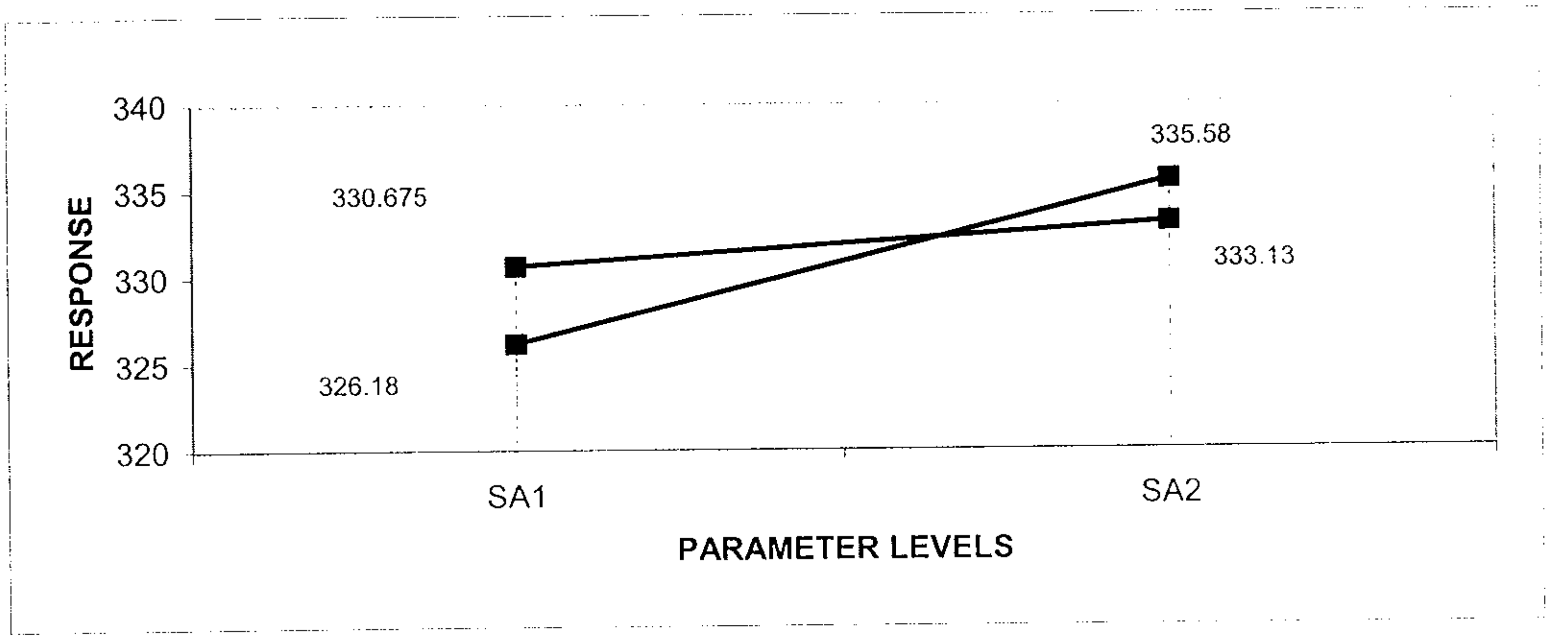


Figure 4.10 SA Interaction

Average Response Table – Interaction Effect of Parameters

I. (A) Closed single v – Groove Joint (Electrode Consumption in cm/m)

IS Interaction

Table 4.20

Levels For Factors		Observed Response	Average Response
I	S		
1	1	126+150	138
1	2	186+224	205
2	1	176+210	193
2	2	122+134	128

IA Interaction

Table 4.21

Levels For Factors		Observed Response	Average Response
I	A		
1	1	126+186	156
1	2	150+224	187
2	1	176+122	149
2	2	210+134	172

SA Interaction

Table 4.22

Levels For Factors		Observed Response	Average Response
S	A		
1	1	126+176	151
1	2	150+210	180
2	1	186+122	154
2	2	224+134	179

Average Response Graph – Interaction Effect of Parameters

I. (A) Closed single v – Groove Joint (Electrode Consumption in cm/m)

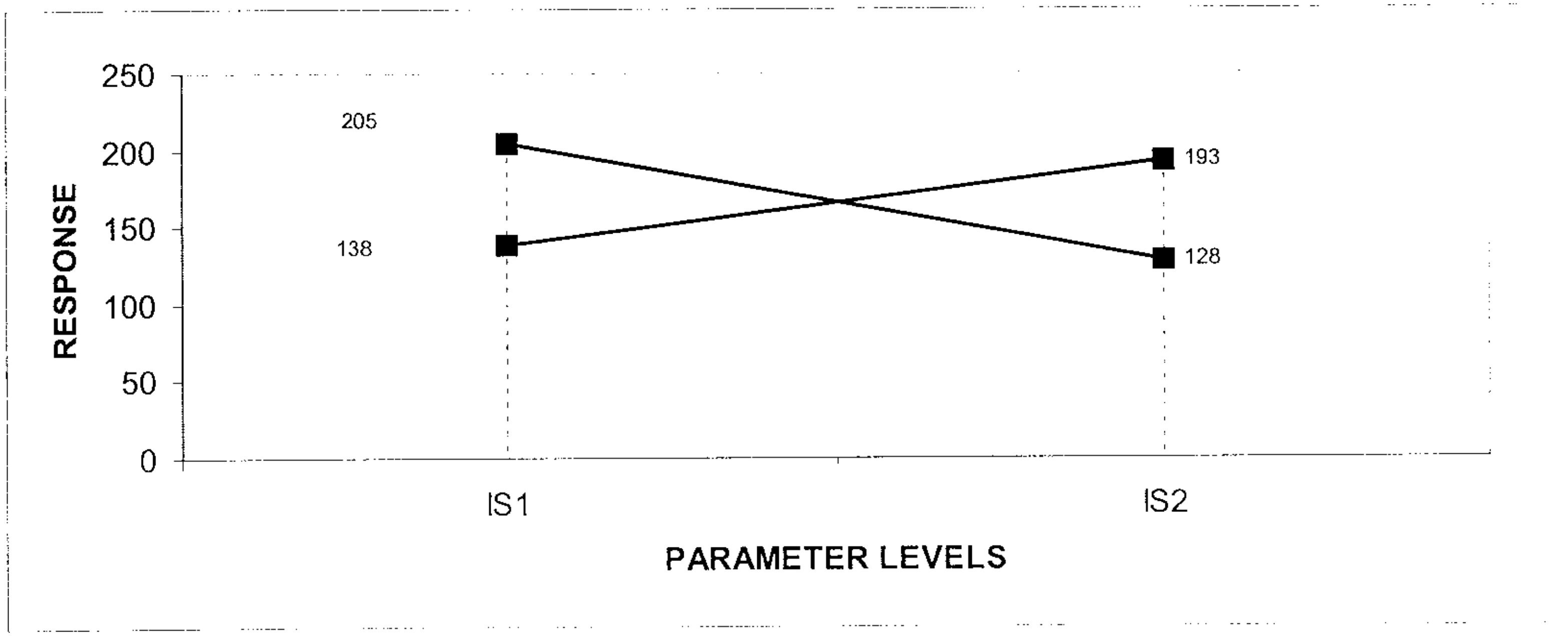


Figure 4.11 IS Interaction

Average Response Graph – Interaction Effect of Parameters

I. (A) Closed single v – Groove Joint (Electrode Consumption in cm/m)

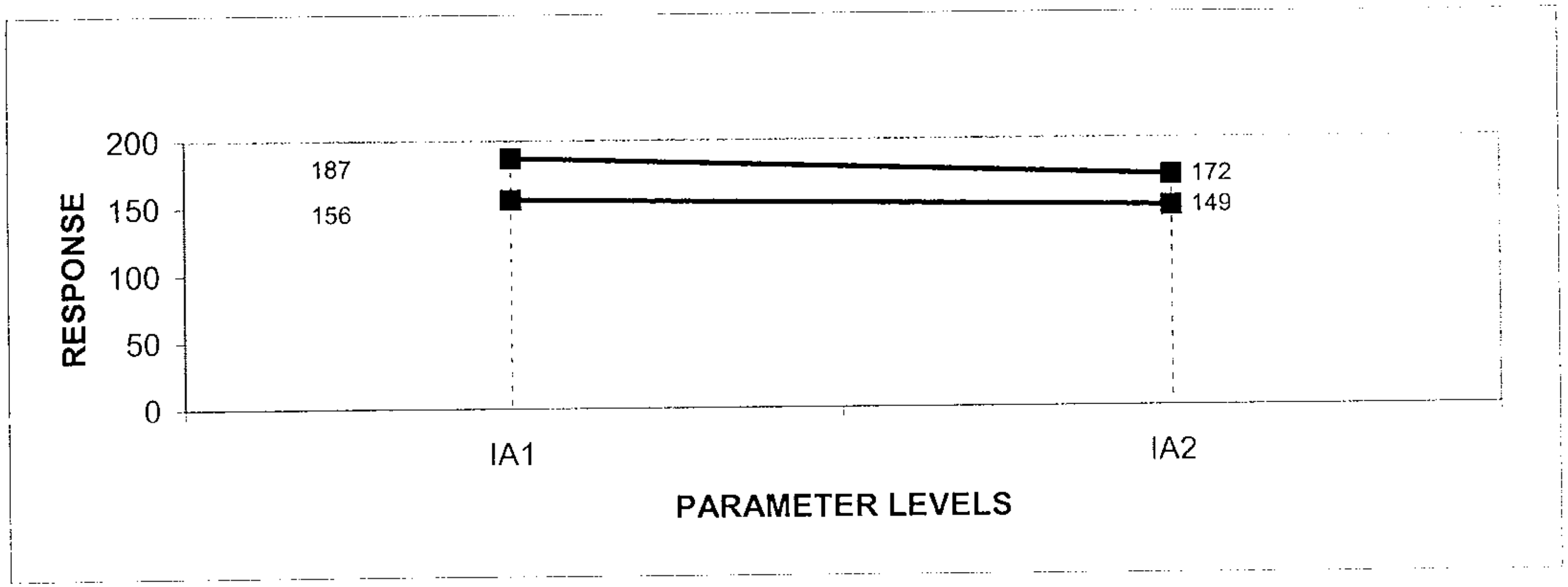


Figure 4.I2 IA Interaction

Average Response Graph – Interaction Effect of Parameters

I. (A) Closed single v – Groove Joint (Electrode Consumption in cm/m)

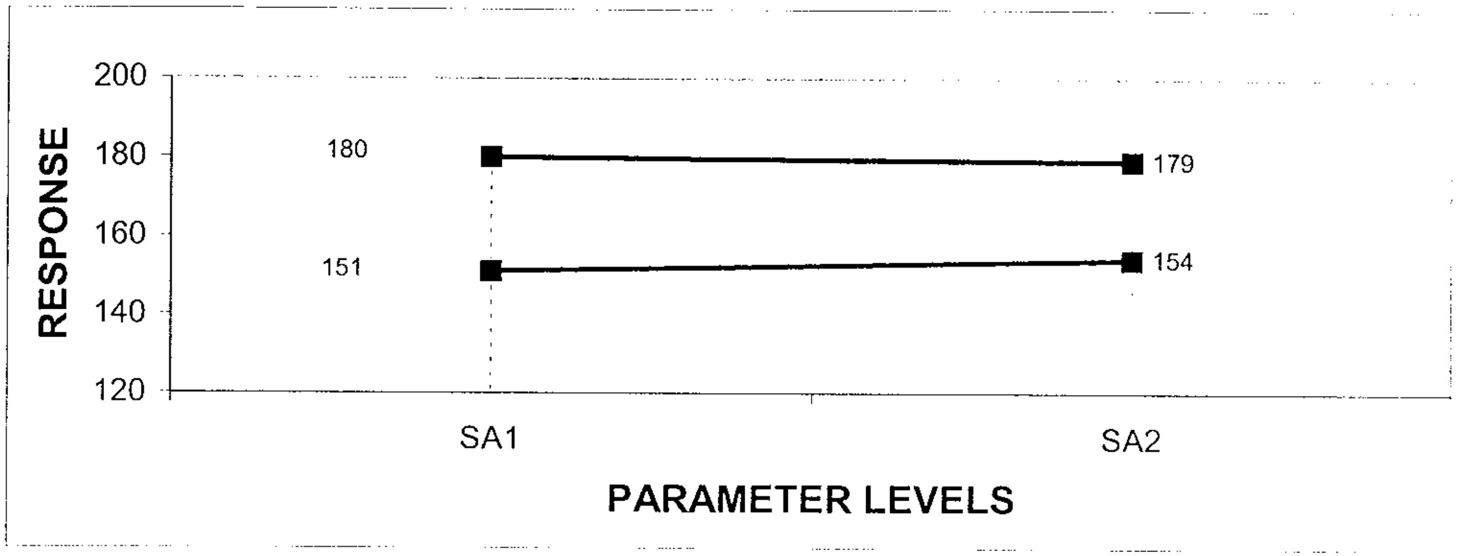


Figure 4.13 SA Interaction

Average Response Table – Interaction Effect of Parameters

I. (B) Closed Single V – Groove Joint (Weld Strength in N/mm^2)

IS Interaction

Table 4.23

Levels For Factors		Observed Response	Average Response
I	S		
1	1	255.87+326	290.93
1	2	298.38+261.6	279.99
2	1	296.75+327.81	312.28
2	2	327+301.65	314.32

IA Interaction

Table 4.24

Levels For Factors		Observed Response	Average Response
I	A		
1	1	255.87+298.38	277.12
1	2	326+261.6	293.8
2	1	296.75+327	311.87
2	2	327.81+301.65	314.73

SA Interaction

Table 4.25

Levels For Factors		Observed Response	Average Response
S	A		
1	1	255.87+296.75	276.31
1	2	326+327.81	326.90
2	1	298.38+327	312.69
2	2	261.6+301.65	281.62

Average Response Graph – Interaction Effect of Parameters

I. (B) Closed Single V – Groove Joint (Weld Strength in N/mm^2)

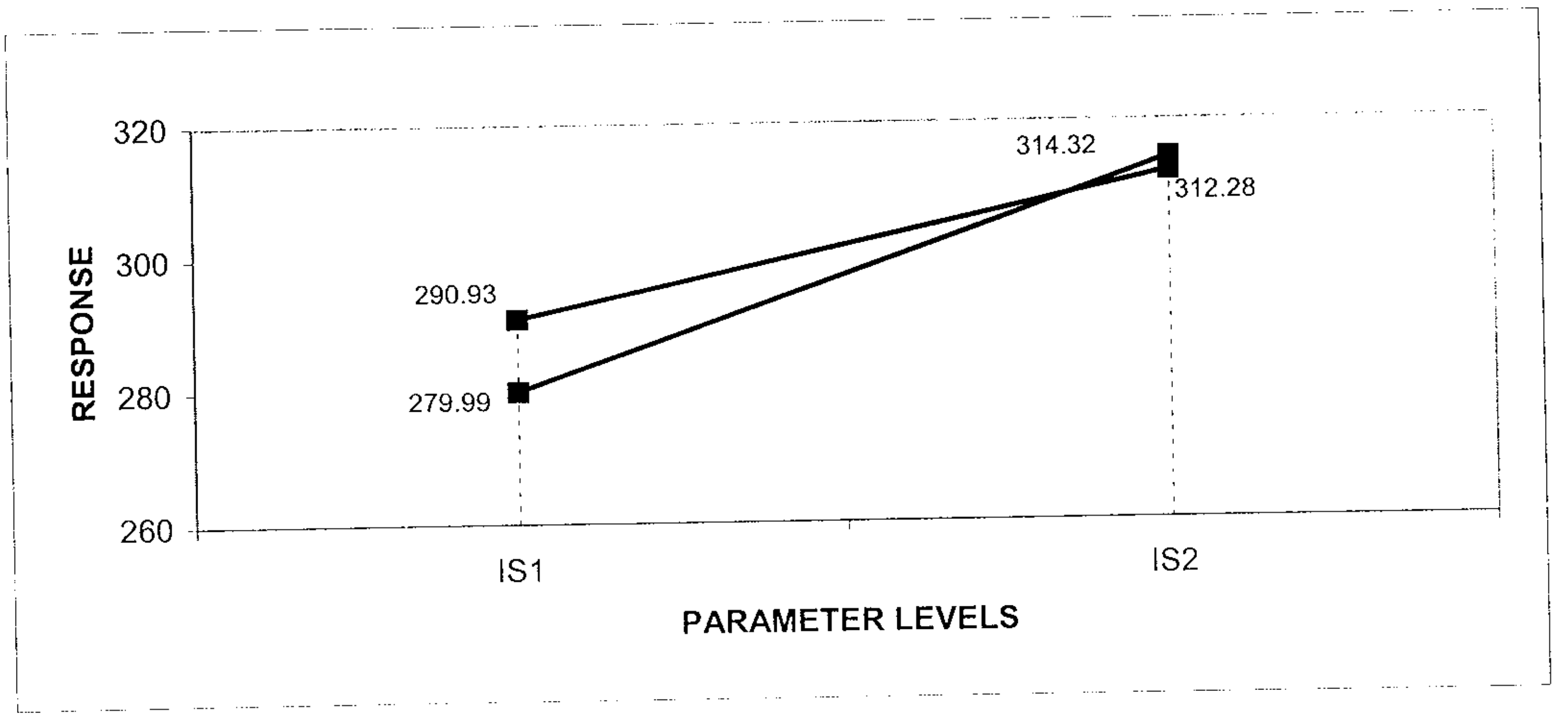


Figure 4.14 IS Interaction

Average Response Graph – Interaction Effect of Parameters

I. (B) Closed Single V – Groove Joint (Weld Strength in N/mm^2)

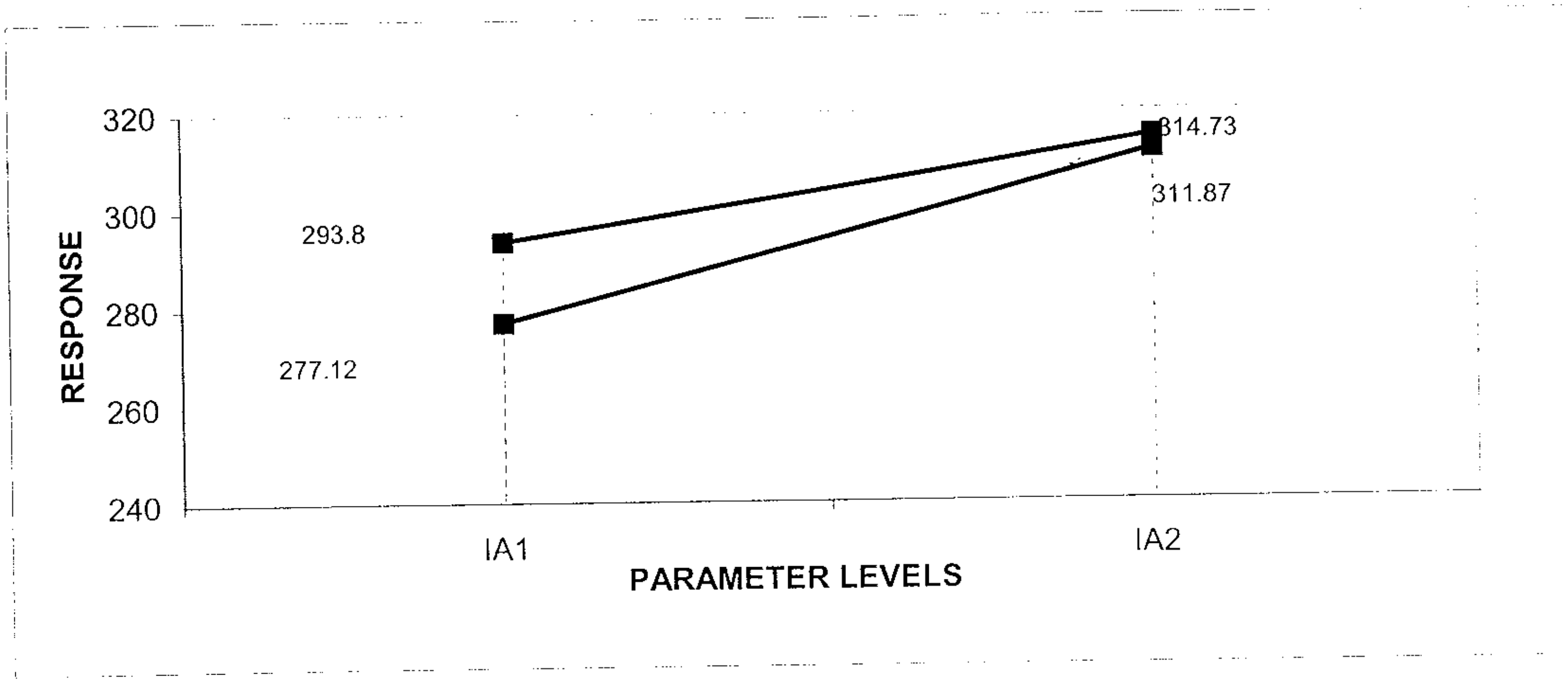


Figure 4.15 IA Interaction

Average Response Graph – Interaction Effect of Parameters

I. (B) Closed Single V – Groove Joint (Weld Strength in N/mm^2)

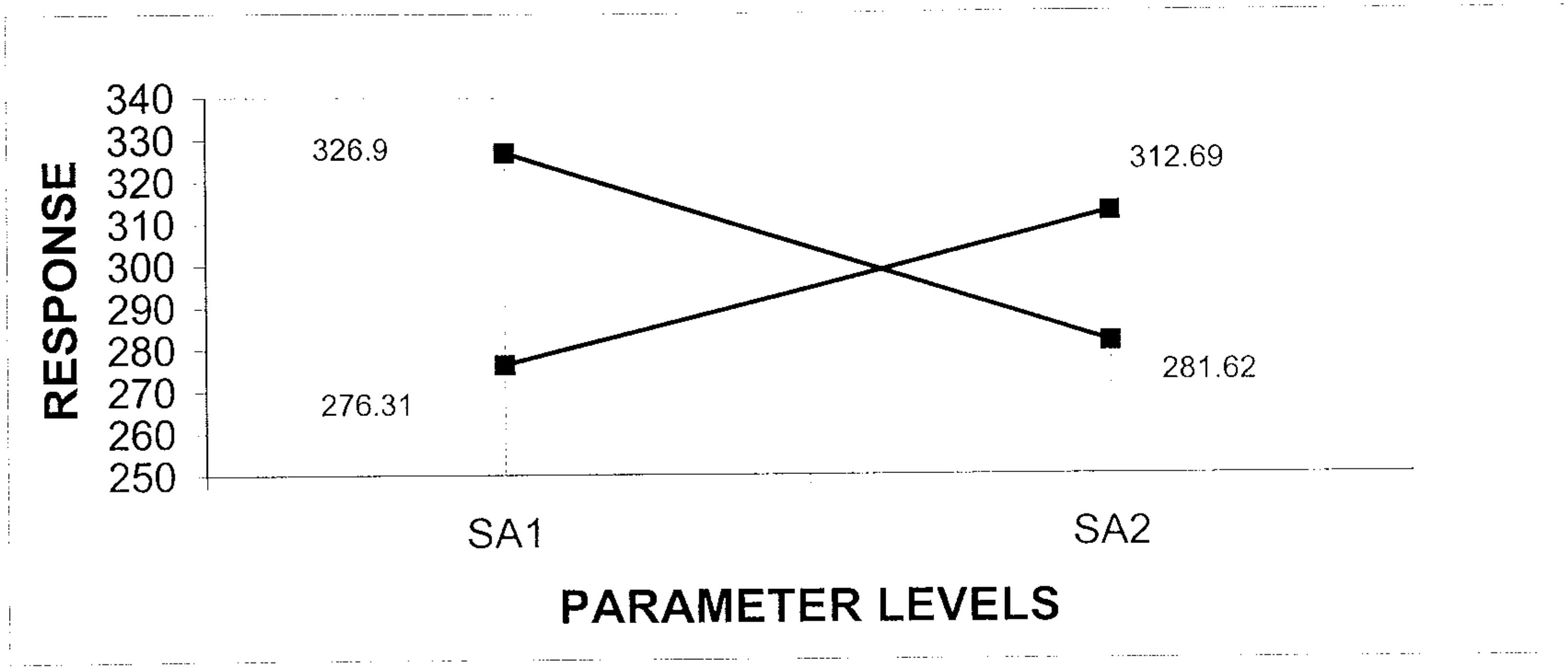


Figure 4.16 SA Interaction

OPTIMIZATION OF PARAMETERS AND THEIR RESPONSE

(By Considering Interaction Effect of Parameters on Response)

I. Open Single V- Groove Joint

A. Electrode Consumption in cm/m of weld

From the above rule [2], the "IS" combination is having strong interaction than other. Hence, it is advisable to select the "IS" combination for optimization. Similarly, from the main effect graph it was found that "A "having more impact on the response. It is given by the formula,

Ybar min = grand mean of all responses + I and S contribution + A contribution.

= 189 + (158*-189) + (180+189)

= 149 cm/m

* 158 is chosen from the average response table of "IS" i.e., select minimum average response value among all the values corresponding levels of I and S are 1 and 1 respectively.

Optimization of Parameters

The parameter levels for I and S are selected from average response table for "IS" corresponding to the values of 158 as

Welding current (I) = 125 Amps

Welding speed(S) = 5.4 m/min

Joint angle (A) = 50°

II. Closed Single V- Groove Joint

A. Electrode Consumption in cm/m of weld

The "IS" combination is having strong interaction than other. Hence, it is advisable to select the "IS" combination for optimization. Similarly, from the main effect graph it was found that "A "having more impact on the response. It is given by the formula,

Ybar min = Grand mean of all responses + I and S contribution + A contribution.

= 166 + (128*-166) + (160.50+166)

= 122.50 cm/m

* 128 is chosen from the average response table of "IS" i.e., select minimum average response value among all the values corresponding levels of I and S are 2 and 2 respectively.

Optimization of Parameters

The parameter levels for I and S are selected from average response table for "IS" corresponding to the values of 3128 as

Welding current (I) = 150 Amps

Welding speed (S) = 8.3 m/min

Joint angle (A) = 70°

II. Optimization of Response for Closed Single V- Groove Joint

B. Weld Strength

Similarly, "IS "combination is having strong interaction than other. Hence, it is advisable to select the "IS" combination for optimization. Similarly, from the main effect graph it was found that "A "having more impact on the response. It is given by the formula,

Ybar max = Grand mean of all responses + I and S contribution + A contribution.

= 299.38 + (314 –299.38) + (313.30 – 299.38)

= 327.32 N/mm^2

* 314 is chosen from the average response table of "IS" i.e., select minimum average response value among all the values corresponding levels of I and S are 2 and 2 respectively.

Optimization of Parameters

The parameter levels for I and S are selected from average response table for "IS" corresponding to the values of 314 as

Welding current (I) = 150 Amps

Welding speed (S) = 8.3 m/min

Joint angle (A) = 70°

RESULTS AND DISCUSSIONS

The entire fabrication process was studied and the most influencing process parameters were identified. They include:

1. Welding current (I)
2. Welding speed (S)
3. Joint angle (A)

To produce more meters of weld in a given frame of time a set of experiments were conducted using the orthogonal array and the responses were recorded for two types of weld joints. They include:

1. Electrode consumption (Y_c)
2. Welding strength (Y_s)

Recorded responses and process parameters were analyzed and the main effect and the interaction effect of those parameters are given in the graphical form. And the optimized parameters and responses were found out by using these graphs.

Optimized parameters and responses are as follows:

1. Open Single V- Groove Joint

A. Optimized Electrode Consumption Yc= 149 cm/m of weld

Optimized Parameters

Welding Current = 125 Amps

Welding Speed = 5.4 m/min

Joint Angle = 50 degree

CONCLUSION

The following conclusions were arrived at from the above investigations.

Closed single V-Groove joint consumes fewer electrodes and also covers more meter of weld. With the same process parameter, it gives more strength. Hence it advisable to select the closed single v-groove joint for this fabrication.

The optimized parameters and responses are:

Closed Single V-Groove Joint

A. Optimized electrode consumption Yc = 122.5 cm/m of weld

Optimized Parameters

Welding Current = 150 Amps
Welding Speed = 8.3 m/min
Joint Angle = 70 degree

B.Optimized Weld Strength Ys = 327.32 N/mm^2

These experiments are useful in optimizing the process control parameters and improving welding productivity at a competitive welding cost.

BIBILIOGRAPHY

Journals

[1] Ali Bazzi,"*Means for Increasing Productivity*", Lincoln Electric Co.(Australia) Pvt Ltd,Stdney.

[2] Bruse Sterling,"*Meeting the Welding Productivity Challenges*",The Lincoln Electric Company,Ohio,U.S.A.

[3] Gunaraj.V,Murugan.N,"*Application of Response Surface Methodology for Predicting Weld Bead Quality In Submerged Arc Welding of Pipes*",Journal of Materials Processing Technology" 88(1999) 266-275

[4] Rajasekeran.N,Sethuraman.A,"*Waste Management in Welding*",WRI Journal,1999 vol – 20 no 1,BHEL,Thiruchirapalli.

[5] Venkataraman.R,"*Welding Economics and Productivity*",WRI Journal,1999, BHEL,Thiruchirapalli.

Books

[6] Coharan & Cox,"*Experimental Design*",Prentice Hall,New Jersey 1992.

[7] Genichi Taguchi,"*Taguchi Methods Explained Practical Steps to Robust Design*",Mc Graw-Hill Book Company,1989.

[8] Rao.S.S,"*Optimization Thory and Application*",Wiley Eastern Ltd.,