DEVELOPING A BEAD GEOMETRY BASED CRITERION FOR SELECTION OF PROCESS PARAMETERS OF METAL INERT GAS (MIG) WELDING USING TAGUCHI TECHNIQUES

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ABSTRACT : *Metal inert gas (MIG) welding is a fusion welding process having wide applications in industry. In any welding process, proper selection of input parameters is necessary to obtain good quality welds and consequently, increase the productivity of the process. Invariably, quality of welds is specified in terms of their ability to meet the service load requirements, zero-defect condition and/or cost-effective production. However, it is observed that a 'Good Weld Bead Geometry' can often be used to stipulate the weld quality as well as ensures one or more of the former considerations. The weld bead geometry is expressed in terms of six output parameters (called responses), viz., height of reinforcement (R), depth of penetration (P), weld bead width (W), per cent dilution (%D) and shape relationships such as weld penetration shape factor (W/P) and weld reinforcement form factor (W/R). This paper reports the experimental work with regard to developing a bead geometry-based criterion for acceptance of weldments prepared by MIG. Taguchi design method, comprising L16 orthogonal array (OA) was used to conduct the experimental with two replications and graphical method of analysis was used to arrive at the optimum combination of process parameters. The Responses were expressed in terms of six input process parameters, namely, wire feed rate (WFR), arc voltage (V), welding speed (WS), stand-off-distance (SOD), shielding gas flow rate (GFR) and parent material plate thickness (PT). Influence of the six main factors and their two-factor interactions were studied and the results are presented. It is observed that an increase in parameters like wire feed rate, welding speed, SOD and plate thickness will also result in a corresponding increase in reinforcement while they affect penetration in a negative way. On the other hand, a decrease in arc voltage results in an increase in reinforcement, but penetration decreases. The effect of GFR is typical, in the sense, as it is increased reinforcement decreases, but penetration shows an increasing trend. Further, weld bead width shows a positive correspondence with almost all input parameters. But, it has a negative relationship with SOD while it is unaffected by GFR. Also, the effect of 2-factor interactions have been studied and presented in this paper.*

Keywords: MIG welding, Bead geometry, Taguchi method

1. INTRODUCTION

Metal Inert Gas welding is one of the most widely used welding processes in the industries both for production and repair welding of ferrous as well as non-ferrous structurals and/or components. It is observed that the quality and strength of the MIG welded joints is governed by a host of process parameters (often called input parameters). In fact, it is possible to identify and specify a few weld bead geometry parameters which reflect the complexity of welding in addition to giving firsthand information about the quality, time and cost of fabrication of any welded structure. Therefore, it is imperative to understand the nature and influence of such process parameters on the intended service capability of welds (termed as responses). Further, a perfect arc produced by employing the optimum input parameters is believed to provide a quick way of ensuring the quality and conformity with standards specified by a customer. A project has been undertaken to develop the welding procedure and ensure production of high quality MIG welds with a view to helping the user industries enhance their production in an economical manner. This work is a part of this project. In this, an experimental study is carried out to establish the so called 'Bead Geometry Criterion' leading acceptance of welds without actually going through the tedious process performing of destructive examination, which results in the loss of material, cost and time. It is believed that once the welds are produced based on the established bead geometry criterion, only a few specimens may be subjected to various service weldability tests. In this contest, the entire work producing the MIG welds is done employing Taguchi method. The details are presented in the following sections.

Literature Review

S. R. Patil and C. A. Waghmare [1] have investigated the effect of main input welding parameters on the tensile strength of welded joint in gas metal arc welding process. They have shown that among main input welding parameters the effect of welding speed is significant. R. Chotěborský et al [2] have reported that a five-level factorial technique can be employed easily for developing mathematical models for predicting weld bead geometry within the optimal region of control parameters for hard facing. M. Aghakhani et al [3] have shown that Taguchi's robust orthogonal array design method is suitable to analyze gas metal arc (GMA) welding process as it is a simple, systematic and efficient methodology for the optimization of welding parameters. S. V. Sapakal [4] observed that the Taguchi optimization method can be use to find the optimal process parameters for penetration. L. Suresh Kumar [5] found that hardness of the austenitic stainless steel when welded with TIG process was 162.53BHN; while, welds produced by MIG welding possessed a hardness of 196.54BHN. This showed that MIG welding can be successfully used for hardfacing.

It is observed from the available literature that though some work on assessment of MIG welded joints is available, no systematic study has been conducted to evaluate the main and interaction effects of MIG welds based on bead geometry. Hence, this work was undertaken by the authors. As mentioned earlier, the bead geometry criterion was developed with a

View to providing an easy way to produce better quality welds.

2. METHODOLOGY

The methodology employed to carry out the present work is detailed below.

1. Identifying the range of process parameters, namely, WFR, V, WS, SOD, GFR and PT.
2. Developing the design matrix based on L16 Orthogonal Arrays (OA) to provide a set of well balanced experiments.
3. Conducting experiments according to the design matrix under various combinations of the six parameters and their interactions.
4. Evaluating the effect of main factors and their 2-factor interactions on bead geometry parameters like P, R, W and %D. Also, evaluating the shape relationships, namely, WPSF and WRFF.
5. Recording of the responses and analyzing the same using graphical technique to obtain the optimum combination of process parameters that gives the desired responses.

2.1 Identify the range of process parameters

In the present study, in order to identify the range of process parameters, a preliminary experimentation was carried out. Bead-on-plate weld were produced by varying the identified parameters over a large range, and the upper and lower limits of the six input parameters which resulted in 'Good-Looking' weld beads, were selected for further experimentation. Table 1 shows the range of these parameters

2.2 Developing the design matrix

As per Taguchi method, design matrix was written based on L16 orthogonal array, and the same is presented in Table 2. Both coded and actual notations are shown for the parameters. X1, X2, X3, X4, X5 and X6 refer to the main factors, WFR, V, WS, SOD, GFR and PT. Their 2-factor interactions are represented as the product of the 2 factors under consideration. Thus, 2-factor interaction of X1 and X2 is represented as X1*X2 (WFR*V) and so on. The lower limit of the factor is indicated by 1, and the upper limit of the same is indicated by 2.

3. EXPERIMENTAL PROGRAMME

The experimental programme comprised laying bead-on-plate weld by a semiautomatic MIG welding machine using AC power supply. Surfaces of all the MS plates were ground to remove oxide scale and dirt. Consumable electrode in the form of 1.2 mm diameter copper-coated MS wire was used for depositing weld beads on the base metal. Shielding of the gas puddle and molten metal droplets was carried out by CO_2.

3.1 Preparation bead-on-plates

Large size plates in the as-received condition were cut-to-size (200×100×6mm and 200×100×8mm) by a power hacksaw and cleaned by wire-brush were used to place 4 beads on each plate following the design matrix Table 2). Also, laying of weld beads was replicated twice so as to ensure repeatability of observations. In all, for each thickness (6mm and 8mm), three sets of bead-on-plates (totaling six welded plates with one plus two replicates) were produced using various combinations of the six welding parameters. Each of the welded plates was cross-sectioned from defect-free regions to obtain test specimen of about 30x15x6mm thickness and 30x15x8mm thickness. These specimens were subjected to usual metallurgical studies like cleaning, polishing and etching (with 2% Nital). The geometry of the weld beads were measured using a profile projector to obtain height of reinforcement (R), depth of penetration (P) and weld bead width (W). Weld penetration Shape Factor (W/P) and Weld Reinforcement Form Factor (W/R) were calculated based on the above information. Also, area of reinforcement (A_R) and area of penetration (A_P) were measured and %dilution was calculated using these values. Table 3 shows the levels of individual process parameters and the average responses for each case. All the welding was done at room temperature and under laboratory Conditions. Photographs of a few welds are shown in figure 1 and 2

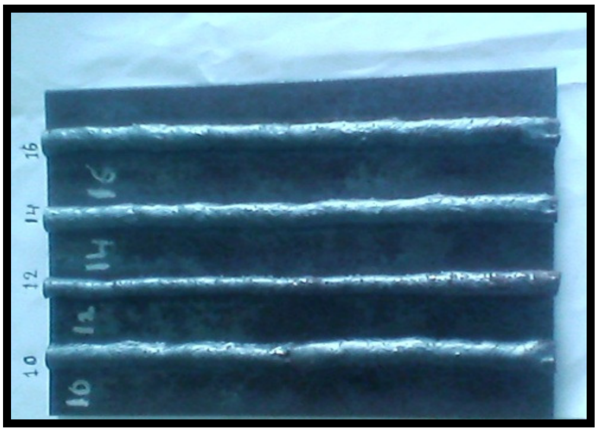

Fig. 1 Ordered Set

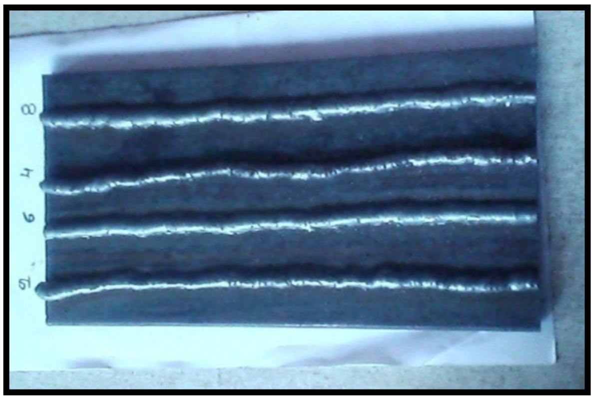

Fig. 2 Disordered Set

Fig. 3 after etching (order runs)

Fig. 4 After etching (disorder runs)

For the sake of convenience the welds were divided into two groups (ordered and disordered) to make it carry out further examination. Ordered-run specimens were cut into 1-bead pieces and the disordered-run specimens were cut into 2-bead pieces to identify easily and to enable easy polishing, etching, etc. These were then polished on metallographic polishing papers of grades 230, 400, 500, respectively till a faint image of the beads revealing depth of penetration and HAZ was noticed on each piece. They were polished for fine finish on lapping discs and etched with 2% nital which was prepared fresh.

4. RESULTS AND DISCUSSION

All the beads on the plates were traced using a profile projector. Typical bead shapes showing various bead geometry parameters are shown in Figure 5. The parameters were measured and average values are recorded in the Table 3. The results of the study show that all the welding parameters have considerable effect on the responses, both in their individual capacity and in terms of the 2-factor effects. Using the information of Table 3 graphical representations were made. The details of the graphs and a brief description of each one is presented below.

4.1 Analysis of graphical results

Both main and interaction effects are discussed separately using graphical representation.

Figure 5 shows that as WFR, V, GFR, and PT are increased from level 1 to level 2 there is corresponding increase in penetration. On the other hand, as the remaining two parameters (WS, SOD) were decreased from level 1 to level 2, the penetration also decreased. The slope of the relations for GFR and V is almost same indicating that their influence on depth of penetration is same.

Average value of depth of penetration ($\bar{Y}$) = P_{Avg} = 1.77mm

Optimum condition:

WFR1, V1, WS2, SOD2, GFR1, PT1

Figure 6 shows the main effect of parameters on height of reinforcement (R). It is noticed that increase in WFR, WS, SOD, PT from level 1 to 2 will result in increase of height of reinforcement. But reinforcement decreases as V and GFR are decreased from level 1 to 2. Further, wire feed rate has the greatest effect as seen from its slope.

Average value of height of reinforcement ($\bar{Y}$) = R_{Avg} = 4.32mm

Optimum condition:

WFR2, V1, WS2, SOD2, GFR1, PT2

The main effect of welding parameters on weld bead width (W) is shown in figure 7. It is noticed that WFR, V, WS, PT have positive effect on weld bead width, while that of SOD is negative. Interestingly, GFR has a neutral effect on W, it remains unaffected. Also, effect of WFR and WS on W is almost same, as indicated by the slopes of the corresponding graphs.

Average value of weld bead width

($\bar{Y}$) = W_{Avg} = 6.5mm

Optimum condition:

WFR2, V2, WS2, SOD1, GFR1, PT2

The effect various parameters on W/P are shown in Figures 8. It is seen from the figure that W/P is directly proportional to WS, GFR and PT. But, WFR, V and SOD show a reverse trend. While WS and PT affect W/P severely, SOD has the least effect on W/P.

Average value of weld penetration shape factor:

($\bar{Y}$) = $(W/P)_{Avg}$ = 26mm

Optimum condition:

WFR1, V1, WS2, SOD1, GFR2, PT2

Figure 9 shows that except WFR and SOD all the parameters have a positive effect on W/R. The voltage is the influential parameter and has the greatest influence on W/R.

Average value of weld reinforcement

Form factor:

($\bar{Y}$) = $(W/R)_{Avg}$ = 9.31mm

Optimum condition:

WFR1, V2, WS2, SOD1, GFR2, PT2.

Figure 10 shows that minimum %D can be obtained on 8mm thick plate by suitable selection of all the parameters.

Average value of percentage of dilution ($\bar{Y}$) = $\%D_{Avg}$ = 31.46mm

Optimum condition: WFR1, V2, WS1, SOD2, GFR1, PT2

Effect of 2-factor Interactions on bead geometry & shape relationships

In order to understand the actual condition of welding it is essential to assess the influence of main as well as interaction effects of various factors on both bead geometry parameters and shape relationships. Hence, it was decided to draw the graphical relations corresponding to 2-factor interactions on few selected responses. The same are presented in figures 11 to 16.

Figure 11 shows that as WFR*V, WFR*SOD, WFR*PT, SOD*GFR, WS*PT, and WS*GFR are increased from level 1 to level 2 there is corresponding increase in penetration. As the remaining parameters (WFR*WS, V*PT, SOD*PT) were decreased from level 1 to level 2 the penetration also decreased. The slope of the relations for WFR*SOD, WFR*PT, and SOD*GFR is almost same indicating that their influence on depth of penetration is same.

Average value of depth of penetration ($\bar{Y}$) = P_{Avg} = 1.77mm

Optimum condition:

$WFR*V_1$, $WFR*WS_2$, $WFR*SOD_1$, $WFR*PT_1$, $V*PT_2$, $SOD*GFR_1$, $WS*PT_1$, $WS*GFR_1$, $SOD*PT_2$

Figure 12 shows the interactions of parameters on height of reinforcement (R). It is noticed that increase in WFR*PT, WS*PT, SOD*PT from level 1 to 2 will result in increase of height of reinforcement. But reinforcement decreases as WFR*V, WFR*WS, V*PT, and WS*GFR are decreased from level 1

Average value of height of reinforcement ($\bar{Y}$) = R_{Avg} = 4.32mm

Optimum condition:

$(WFR*V)_1$, $(WFR*WS)_1$, $(WFR*SOD)_1$, $(WFR*PT)_2$, $(V*PT)_1$, $(SOD*GFR)_2$, $(WS*PT)_2$, $(WS*GFR)_1$, (SOD*PT).

The interaction of welding parameters on weld bead width (W) is shown in figure 13. It is noticed that WFR*V, WFR*SOD, WFR*PT, SOD*GFR, WS*GFR have positive effect on weld bead width, while that of WFR*WS, V*PT, WS*PT, SOD*PT is negative. Also, effect of SOD*GFR and WS*GFR on W is almost same, as indicated by the slopes of the corresponding graphs.

Average value of bead width

($\bar{Y}$) = W_{Avg} = 6.5mm

Optimum condition:

$(WFR*V)_2$, $(WFR*WS)_1$, $(WFR*SOD)_2$, $(WFR*PT)_2$, $(V*PT)_1$, $(SOD*GFR)_2$, $(WS*PT)_1$, $(WS*GFR)_2$, $(SOD*PT)_{1.}$

The effect various parameters on W/P is shown in Figures 14. It is seen from the figure that W/P is directly proportional to WFR*WS, V*PT, SOD*GFR, WS*GFR. But, WFR*V, WFR*SOD, WFR*PT, WS*PT and SOD*PT show a reverse trend. While WFR*WS and V*PT affect W/P severely, SOD*GFR and WS*GFR has the least effect on W/P. **Average value of weld penetration shape factor = ($\bar{Y}$) = W/P_{Avg} = 26mm**

Optimum condition:

$(WFR*V)_1$, $(WFR*WS)_2$, $(WFR*SOD)_1$, $(WFR*PT)_1$, $(V*PT)_2$, $(SOD*GFR)_2$, $(WS*PT)_1$, $(WS*GFR)_1$, $(SOD*PT)_1$

Figure 15 shows that WFR*V, WFR*WS, and V*PT, these interactions are having positive effect to increase the weld reinforcement form factor. And WFR*SOD, WFR*PT, WFR*PT, SOD*GFR, WS*PT, WS*GFR, and SOD*PT these interactions are having negative effect to increase the weld reinforcement form factor. Also, effect of WFR*V and WFR*WS on W/R is almost same, as indicated by the slopes of the corresponding graphs.

Average value of weld reinforcement form factor = ($\bar{Y}$) = W/R_{Avg} = 9.05mm

Optimum condition:

$(WFR*V)_2$, $(WFR*WS)_1$, $(WFR*SOD)_1$, $(WFR*PT)_1$, $(V*PT)_2$, $(SOD*GFR)_1$, $(WS*PT)_1$, $(WS*GFR)_1$, $(SOD*PT)_1$

From figure 16 it is noticed that, the WFR*V, WFR*WS, V*PT, SOD*GFR, and SOD*PT these interactions are having positive effect to increase the percentage of dilution. And WFR*SOD, WFR*PT, WS*PT, WS*GFR these interactions are having negative effect to increase the percentage of dilution.

to 2. And WFR*SOD, and SOD*GFR has no such effect on height of reinforcement. Further, WS*PT, SOD*PT has the greatest positive effect as seen from its slope.

Average value of percentage of dilution ($\bar{Y}$) = $\%D_{Avg}$ = 31.49mm

Optimum condition:

$(WFR*V)_1$, $(WFR*WS)_1$, $(WFR*SOD)_1$, $(WFR*PT)_2$, $(V*PT)_1$, $(SOD*GFR)_1$, $(WS*PT)_2$, $(WS*GFR)_1$, $(SOD*PT)_2$

5. CONCLUSION

Following are some important conclusions drawn from the present work.

1. Taguchi's robust orthogonal array design can be successfully used to develop a simple bead geometry based criterion for selection of MI welding process parameters to obtain the desired responses
2. The average values of all the responses and the optimum conditions for obtaining the desired responses are recorded. They can be used to get the desired values of responses, without actually conducting the experiments.

3. Both main and 2-factor interactions must be considered to predict the best combination of process parameters to get the optimum condition for best responses.

4. A judicious selection of the six identified process parameters can be employed, even by a layman/less skilled welder to obtain the responses.

5. The conclusions are based on bead-on-plate studies, they are suitable for hardfacing work and therefore, it is essential to extend the research work to welded joints with various joint designs to apply it to welded structurals. Further, this it may be necessary to include type of shielding gas, etc.

6. REFERENCES

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TABLES AND FIGURES

Table1: Levels of process parameters

Parameters	**Units**	**Upper Level (1)**	**Lower Level (2)**
Wire feed rate (WFR)	m/min	3	6
Arc voltage (V)	Volts	14	18
Welding speed (WS)	mm/min	1.5	1.9
Stand of distance (SOD)	mm	5	10
Gas flow rate (GFR)	lit/min	8	16
Plate thickness (PT)	mm	6	8

Table2. L16 Orthogonal array (OA) to conduct experimentation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Trial No.	X1 WFR	X2 V	X1* X2 WFR*V	X3 WS	X1*X3 WFR *WS	X4 SOD	X1*X4 WFR* SOD	X1* X6 WFR *PT	X6 PT	X5 GFR	X2* X6 V*PT	X4*X5 SOD* GFR	X3* X6 WS *PT	X3*X5 WS* GFR	X4* X6 SOD *PT
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

Table3: Design Matrix & Observed values of Bead Geometry

Trial No.	X1 WFR (m/min)	X2 Volts (V)	X3 WS (mm/min)	X4 SOD (mm)	X5 GFR (lit/min)	X6 PT (mm)	Weld Bead Geometry parameters				Shape Relations	
							P	R	W	%D	W/P	W/R
1	3	14	1.5	5	8	6	1.5	3.67	5.33	21.4	3.55	1.45
2	3	14	1.5	5	16	8	1.67	4.67	6	13.9	3.59	1.29
3	3	14	1.9	10	8	6	1.67	4.67	6.33	21.5	3.79	1.36
4	3	14	1.9	10	16	8	0.83	4.67	6	38	7.23	1.28
5	3	18	1.5	10	16	6	2	2.67	5.33	41.1	2.62	2.00
6	3	18	1.5	10	8	8	2.17	4	6.67	41.1	3.07	1.67
7	3	18	1.9	5	16	6	1.83	2.67	6	47.6	3.28	2.25
8	3	18	1.9	5	8	8	1.5	2.83	7	36.8	3.89	2.47
9	6	14	1.5	5	8	8	1.5	5.67	5	16.6	3.333	0.88
10	6	14	1.5	5	16	6	2.67	3.5	8.33	50	3.19	2.38
11	6	14	1.9	10	8	8	1	5.67	8	15	8	1.41
12	6	14	1.9	10	16	6	1.67	5.83	6	28	3.59	1.03
13	6	18	1.5	10	16	8	1.83	3.67	6.67	34.2	3.64	1.82
14	6	18	1.5	10	8	6	2	5	5.67	24.2	2.84	1.13
15	6	18	19	5	16	8	2	4.5	8	42.3	4	
16	6	18	1.9	5	8	6	2.5	4.5	7.67	36.3	3.07	1.70

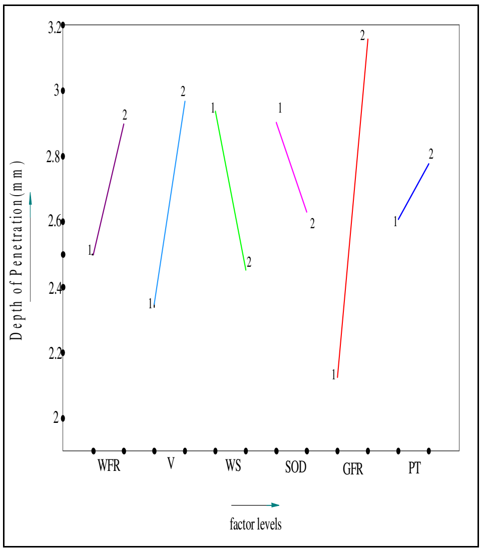

Fig 5 Main effect of factors on depth Of penetration (P)

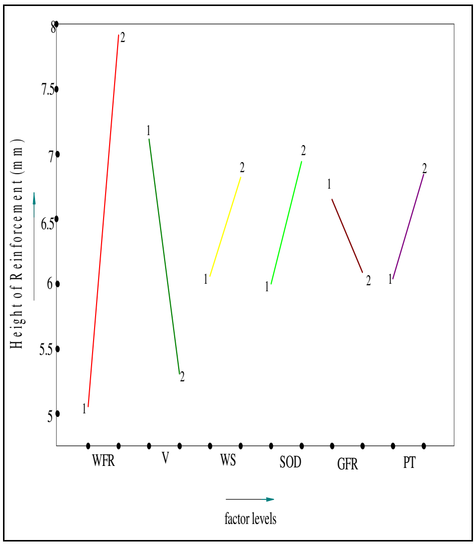

Figure 6 Main effects of parameters on Height of reinforcement (R)

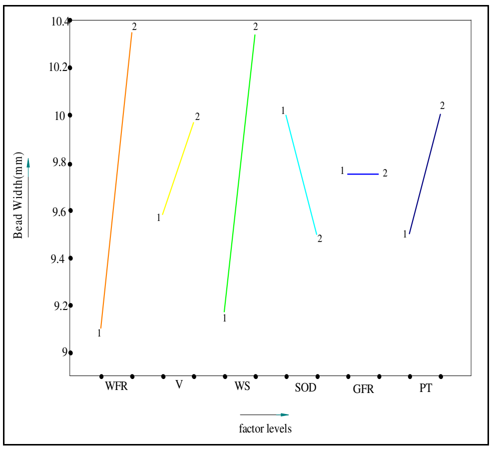

Figure 7 Main Effect of Process parameters on weld bead width (W)

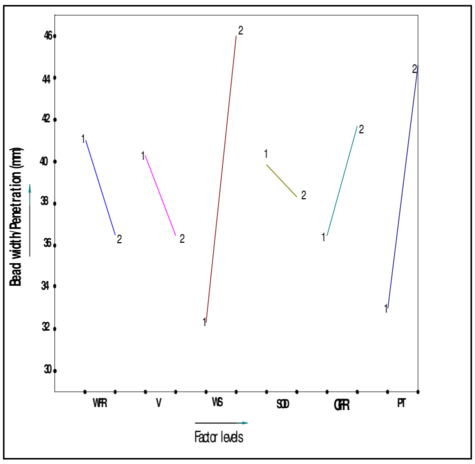

Fig 8 Main effects of parameters on weld penetration shape factor (W/P)

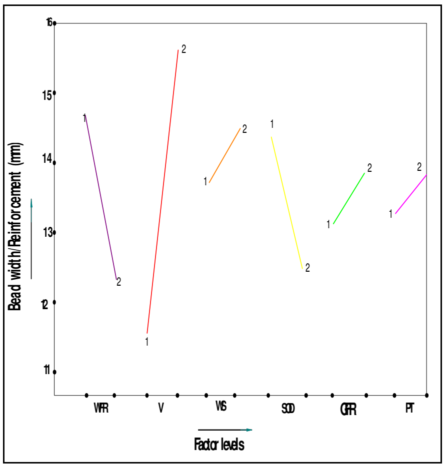

Fig 9Maineffects of parameters on weld reinforcement form factor (W/R)

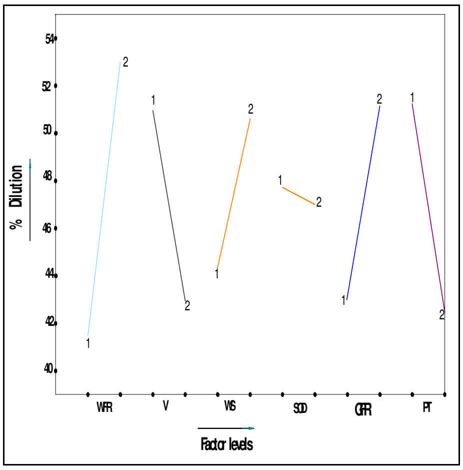

Fig 10 Main effects on percentage dilution(%D)

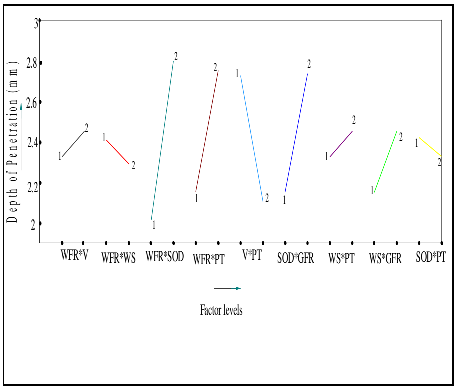

Fig 11 Effect of 2-factor interactions on depth of penetration (P)

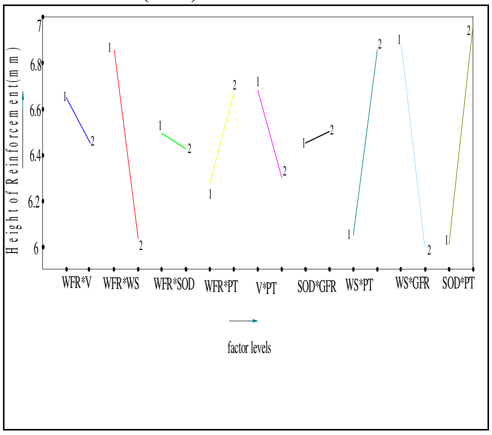

Fig. 12 Effect of 2-factor interactions on height of reinforcement (R)

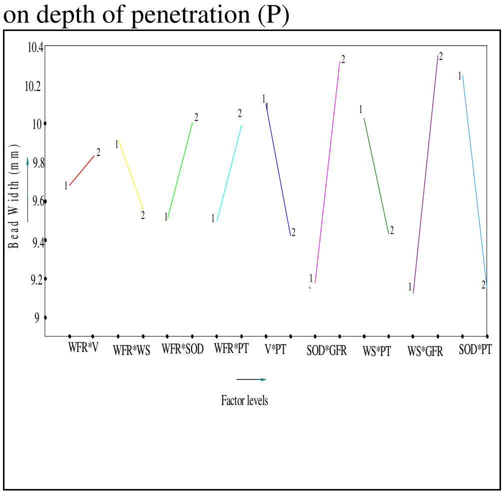

Fig. 13 Effect of 2-factor Interactions on bead width (W)

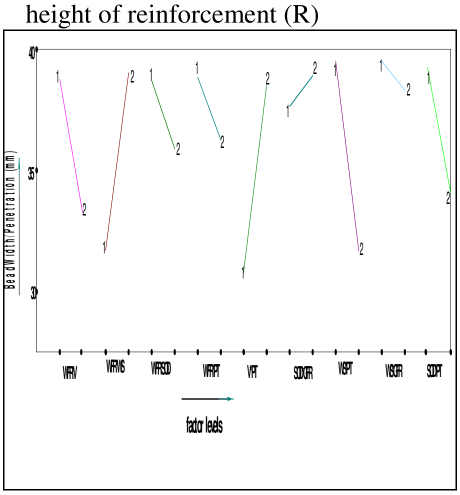

Fig. 14 Effect of 2-factor interactions on weld penetration shape factor (W/P)

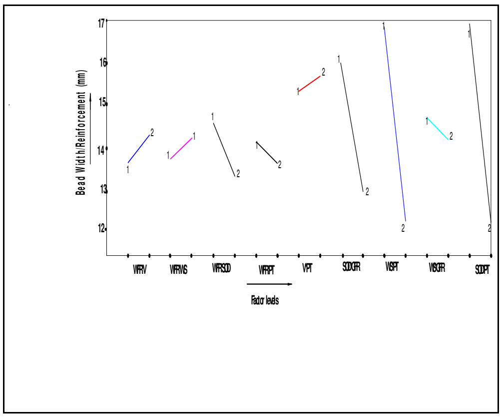

Fig. 15 Effect of 2-factor interactions
On weld reinforcement form factor (W/R)

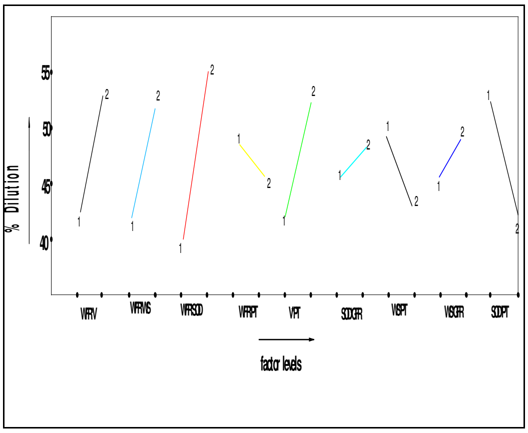

Fig. 16 Effect of 2-factor interactions
on percentage of dilution (%D)