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DEVELOPMENT OF PROCESS SPECIFICATION FOR RADIOGRAPHIC QUALITY WELDING (CAST IRON)

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Key Words

Radiography quality; Cracks; Arc welding; Experiments; Taguchi methods.

Background

Cast-iron welding of radiographic quality is a challenging task. The problem faced here is the emergence of defects like cracks and blow holes during welding. This makes the weld weak. The requirement is to produce defect-free weld quality.

A company manufacturing large electric machines has to carry out the welding on a cast-iron housing for salvaging the finished product. Salvaging becomes essential whenever casting defects like cracks, blow holes, broken ribs, and so forth are observed at the finishing stage of the machine. Here, the rejection of casting amounts to the rejection of other costly assembly materials also. Welding is usually necessitated whenever either a small crack is observed or a small part (rib) is broken during transportation. The current welding process, where cracks and blow holes are observed sometimes on the weld surface, was not acceptable to prestigious customers like the Atomic Energy Commission, the Thermal Power Corporation, and the Power Nuclear Board. Customers want the welding process practiced by the company to assure the radiographic quality.

The problem of determining the process conditions for producing a radiographic quality weld was given the highest priority for investigation, because meeting the customer's requirement was of prime importance to the company. A number of trials were carried out earlier by varying one parameter while others were kept constant. This did not give a satisfactory solution. An exploratory study, using the statistical design of experiment technique, was therefore planned to find a welding technique capable of meeting the radiographic quality standards.

Arc Welding Process

During welding, a V groove is made at the place of welding by the grinding stone/wheel and then the welded metal is fused to the parent metal with the help of an arc. In arc welding, a narrow zone near the welded area attains a very high temperature (arc temperature is 3000°C). During welding, a very small amount of parent metal gets melted near the head of the arc and gets mixed with the molten weld-metal droplet. This mixed molten metal droplet solidifies instantaneously. This creates a high-temperature difference which results in a high cooling rate. Due to this phenomenon, carbide (Fe_3C) formation takes place.

Carbides are responsible for making the casting prone to the development and propagation of cracks.

Factors and Levels for the Experiment

A literature survey of work done on the arc welding process by Taguchi at the Japanese Railway workshop was made. Various electrode manufacturers were consulted to get their views on the process parameters. A senior professor of metallurgy was also consulted for his expert opinion on arc welding processes for cast-iron components.

These discussions with the academician, technologist, and supplier of electrodes and the survey of available literature helped in identifying the factors and their levels for the experiment. One of the factors, preheating of the job, suspected to be strongly influencing the quality of weld could not be considered because of its infeasibility (assembled motor bodies cannot be preheated). Experimentation in welding involves the use of expensive electrodes apart from energy and skilled labor. This puts restrictions on the size of the experiments. Therefore, the number of levels chosen for each experimental factor was a bare minimum of two. The factors and their levels selected for the experiment are given in Table 1.

There are five factors each at two levels. A full factorial would require $2^5 = 32$ trials. An orthogonal array approach was adopted to reduce the number of experimental runs. Five main effects, A, B, C, D, and E, and two interactions, B × D and B × E, were included in the investigation.

The linear graph technique developed by Taguchi is used to design the present experiment. The experiment is designed in an L_8 layout. The linear graph is given in Figure 1 and the layout is given in Table 2. The response considered for the experiment is the length of the crack in a work piece.

Table 1. Factors and Levels

FACTORS	LEVELS 1	2
A Electrode make	1	2
B Current (A)	110	135
C V-groove angle	45°	60°
D Bead length (mm)	20.0	33.3
E Welding method	1	2

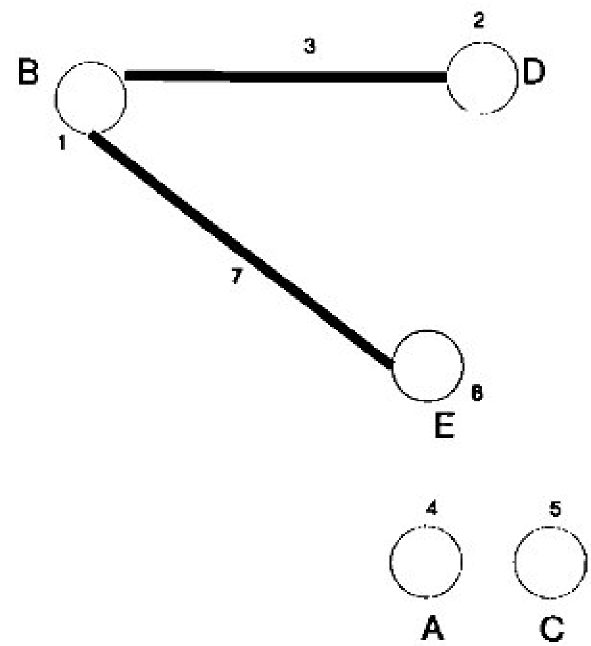

Figure 1. Linear graph.

Preparation for the Experiment

For ease of experimentation, it was decided to conduct this experiment on a cast-iron plate of 25 mm thickness. The thickness of 25 mm was chosen because the section thickness of the castings is normally 25 mm or more. These plates were cast in the foundry with the same grade of metal as used in the motor body casting.

There are two V-groove angles considered in the experiment. Therefore, half of the work pieces were machined to provide one V-groove angle and the other half to pro-

Table 2. Experimental Layout L_8 (2^7)

EXPT. NO.	A (4)	B (1)	C (5)	D (2)	E (6)
1	1	1	1	1	1
2	2	1	2	1	2
3	1	1	1	2	2
4	2	1	2	2	1
5	1	2	2	1	1
6	2	2	1	1	2
7	1	2	2	2	2
8	2	2	1	2	1

vide for the other angle. These V-grooves were ground with a thin grinding stone to create a situation which was similar to actual welding. The two welding methods decided for experimentation are shown in Figures 2 and 3. In welding method 1, the welding process starts from one end and continues until it reaches the other end. In welding method 2, the first welding takes place at the beginning and the second at the middle, the third again at the end of first and the fourth at the end of second, and so on.

Conduction of the Experiment

The order of welding of the work pieces was randomized. Sixteen work pieces, two each for every treatment combination, were welded as per the plan of the experiment.

Cracks developed during welding are often in the internal portion of the casting and usually not visible to the naked eye. Therefore, the weld portion of the work pieces were machined after the welding and sent for x-ray. The x-ray films were viewed under a light to observe and measure the length of the crack. The total length of the cracks on either side of the weld were recorded and are given in the Appendix.

Analysis and Result

Analysis of variance (ANOVA) was carried out on the total lengths of the cracks. The results are given in Table 3.

It can be seen from Table 3 that no main effect is significant. But the interactions between factor B (current) and factor D (bead length), and between factor B and factor E (welding methods) are highly significant. Factor A is found to be significant only at 10%.

The best levels of significant factors were arrived at by comparing the average responses. The average responses were computed and given in Table 4.

Optimum Combination

The results in Table 4 suggest the optimum combination as

$A_1B_2D_1E_1$.

Factor C_1, the groove angle, is considered at the second level for the ease of welding. Thus, the overall optimum is

$A_1B_2C_2D_1E_1$,

that is,

A Electrode make —Make 1
B Current —135 A
C Groove angle —60°
D Bead length —33.3 mm
E Welding method—Method 1

This optimum combination is the same as the condition of experimental trial No. 5. Two pieces were welded in

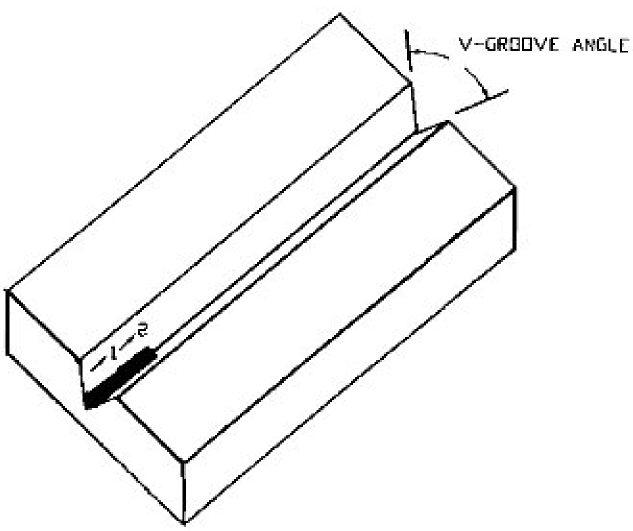

Figure 2. Welding method 1.

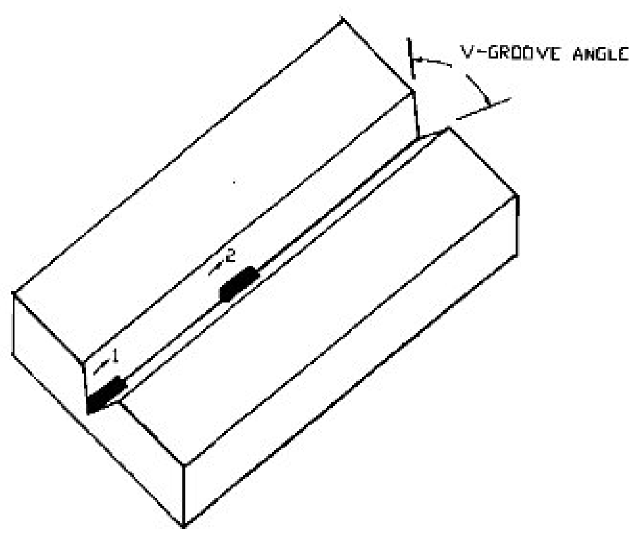

Figure 3. Welding method 2.

Table 3. ANOVA for Cracks

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARE	MEAN SUM OF SQUARE	*F*
A	1	5,625	5,625	4.24[a]
B	1	2,025	2,025	
C	1	3,600	3,600	
D	1	3,600	3,600	
E	1	2,025	2,025	
BD	1	15,625	15,625	11.79[b]
BE	1	22,500	22,500	16.98[c]
STI	7	55,000		
C	8	14,650		
Total	15	69,650		
Pooled error	12	15,900	1,325	

Note: $F_{1,12}$ at 0.05 = 4.75; $F_{1,12}$ at 0.01 = 9.33;; $F_{1,12}$ at 0.10 = 3.14.
[a]Significant at 10%.
[b]Significant at 5% level.
[c]Significant at 1% level.

Table 4. Average Response Table for Significant Factors (Crack Length in mm)

CURRENT (B)	BEAD LENGTH (D) 1	BEAD LENGTH (D) 2	WELDING METHOD (E) 1	WELDING METHOD (E) 2	ELECTRODE MAKE (A)	AVERAGE CRACK LENGTH (mm)
1	115	82.5	147.5	50.0	1	68.75
2	30	122.5	50.0	102.5	2	106.25

experiment No. 5 and no crack was observed in either piece.

Appendix: Data on Total Crack Length

EXPERIMENT NUMBER	REPLICATION 1	REPLICATION 2
1	140	120
2	140	60
3	0	0
4	190	140
5	0	0
6	60	60
7	95	195
8	50	150

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