Optimization of Resistance Spot Welding on Stainless Steel type 304 using Orthogonal Array and ANOVA

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Abstract- *This paper is basically aimed at showing the various parameters of resistance spot welding of stainless steel type 304 using Orthogonal Array Testing Strategy and Analysis of Variance. In this research, the effect and result of spot welding parameters on tensile strength (T.S.) and nugget diameter (N.D.) was investigated using Orthogonal Array Testing Strategy and Analysis of Variance. Optimum results have been obtained using medium current, medium pressure and high holding time.*

Keywords- Resistance Spot Welding, Orthogonal Array Testing Strategy (OATS), ANOVA Method.

I. INTRODUCTION

Resistance Spot welding is a process in which laying surfaces are joined in one or more overlapping spots by the heat generated by resistance to the flow of electric current through the work pieces that are held together under force between the electrodes. The contacting surfaces in the region of current concentration are heated by a short-time pulse of low-voltage, high-amperage current to form a fused nugget of weld metal in between the plates being joined. When the flow of current ceases, the electrode force is still retained while the weld metal rapidly cools and solidifies. The electrodes are retracted after each weld, which usually is completed in a fraction of a second. The experimental studies have been conducted under varying pressure, current & time on quality characteristic, Hardness and Weld life. In this paper, the use of the Orthogonal Array Testing Strategy to determine the optimum process parameters is reported. This is because the Orthogonal Array Testing Strategy is a systematic application of design and analysis of experiments for the Purpose of designing and improving product quality at the design stage. Welding parameters settings were determined by using the Orthogonal Array Testing experimental design method. The level of importance of the welding parameters on the tensile shear strength is determined by using analysis of variance (ANOVA).

II. ORTHOGONAL ARRAY TESTING STRATEGY (OATS) TECHNIQUE

The Orthogonal Array Testing Strategy (OATS) is a systematic, statistical way of testing pair-wise interactions. It provides representative (uniformly distributed) coverage of all variable pair combinations. This makes the technique particularly useful for integration testing of software components (especially in OO systems where multiple subclasses can be substituted as the server for a client). It is also quite useful for testing combinations of configurable options.

Orthogonal arrays were originally discovered as a numerical curiosity by monks. The arrays went largely unnoticed, lying dormant in the aging notes of these monks, until the 1950s. It was then that these "numerical curiosities" were picked up by the statistics community and put to use in statistical test design. Dr. Genichi Taguchi was one of the first proponents of orthogonal arrays in test design [1]. His techniques, known as Taguchi Methods, have been a mainstay in experimental design in manufacturing fields for decades.
Orthogonal arrays are two dimensional arrays of numbers which possess the interesting quality that by choosing any two columns in the array you receive an even distribution of all the pair-wise combinations of values in the array [2]. Here is some terminology for working with orthogonal arrays followed & orthogonal chart [3] presented in Table 1:

Runs: the number of rows in the array. This directly translates to the number of test cases that will be generated by the OATS technique.

Factors: the number of columns in an array. This directly translates to the maximum number of variables that can be handled by this array.

Levels: the maximum number of values that can be taken on by any single factor. An orthogonal array will contain values from 0 to Levels-1.

Strength: the number of columns it takes to see each of the Levels Strength possibilities equally often.

Orthogonal arrays are most often named following the pattern L Runs (Levels Factors).

Table 1. Selection of orthogonal array

Number of Levels					
		2	3	4	5
Numbers of parameters (P)	2	L4	L9	L16	L25
	3	L4	L9	L16	L25
	4	L8	L9	L16	L25
	5	L8	L18	L16	L25
	6	L8	L18	L32	L25
	7	L8	L18	L32	L50
	8	L12	L18	L32	L50
	9	L12	L27	L32	L50
	10	L12	L27	L32	L50
	11	L12	L27		L50
	12	L16	L27		L50
	13	L16	L27		
	14	L16	L36		
	15	L16	L36		
	16	L32	L36		
	17	L32	L36		
	18	L32	L36		
	19	L32	L36		
	20	L32	L36		
	21	L32	L36		
	23	L32	L36		
	24	L32			
	25	L32			
	26	L32			
	27	L32			
	28	L32			
	29	L32			
	30	L32			
	31	L32			

Table 2. An L9 (34) orthogonal array with 9 runs, 4 factors, 3 levels, and strength of 2

	Factors			
Runs	0	0	0	0
	0	1	1	2
	0	2	2	1
	1	0	1	1
	1	1	2	0
	1	2	0	2
	2	0	2	2
	2	1	0	1
	2	2	1	0

In robust engineering, the main role of OAs is to permit engineers to evaluate a product design with respect to robustness against noise and cost involved. The OA is an inspection device to prevent a "poor design" from going "downstream." Arrays can have factors with many levels, although two- and three-level factors are most commonly encountered.

Test case selection poses an interesting dilemma for the software professional. Almost everyone has heard that you can't test quality into a product that testing can only show the existence of defects and never their absence, and that exhaustive testing quickly becomes impossible even in small systems. However, testing is necessary. Being intelligent about which test cases you choose can make all the difference between endlessly executing tests that just aren't likely to find bugs and don't increase your confidence in the system and executing a concise, well-defined set of tests that are likely to uncover most (not all) of the bugs and that give you a great deal more comfort in the quality of your software.

ANALYSIS OF VARIANCE (ANOVA)

The data analysis method for treatment comparison is called analysis of variance (ANOVA), which examines whether the treatments for comparison generate the same (or similar) outcomes. ANOVA was applied on data from tensile-shear, peel, and impact tests separately. The F values and p values are presented in Table 3. An F value in ANOVA is the statistic for evaluating whether the treatment means are equal [4].

TABLE 3. Table of F values and P Values, ANOVA

	F value	P value
TENSILE-SHEAR	25.0815	7.284151e-011
PEEL	27.9803	1.371314e-011
IMPACT	27.9327	1.090872e-011

A large F value implies a significant difference between the treatments [5]. A p value is the probability of obtaining a value that is significantly different from the observed value. Because all the p values are quite small (much smaller than 0.05), it is safe to conclude that the five treatments have significantly different effects on the response. A similar conclusion can be drawn based on the F value. However, ANOVA only tests the hypothesis that these treatments have the same effects. After the hypothesis is rejected, a more interesting question is how they are different. An advanced analysis based on a linear model is required to answer such a question. Before a formal analysis is performed, a graphical analysis using, e.g., box plots, as shown in Figure 1, is helpful. From left to right, the box plots for tensile-shear (TS), peel (P), and then impact (I) tests, as well as for each treatment (T) are drawn.

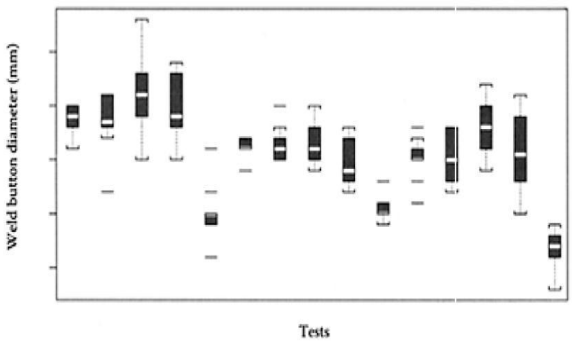

Figure 1. Box plots of diameter for different testing methods and treatments

An ANOVA is an analysis of the variation present in an experiment. It is a test of the hypothesis that the variation in an experiment is no greater than that due to normal variation of individuals' characteristics and error in their measurement.

III. EXPERIMENTAL PROCEDURE

The Process parameters with their values at three levels are shown in the table as follows:-

Table 3

Levels	Current (KA)	Electrode Force (kN)	Time (sec)
1	6.0	0.662	2
2	6.8	0.789	4
3	7.5	0.968	5

The results have been recorded in the above table and analysis the nugget diameter of the welded specimen. The following figures show the method for achieving nugget diameter length.

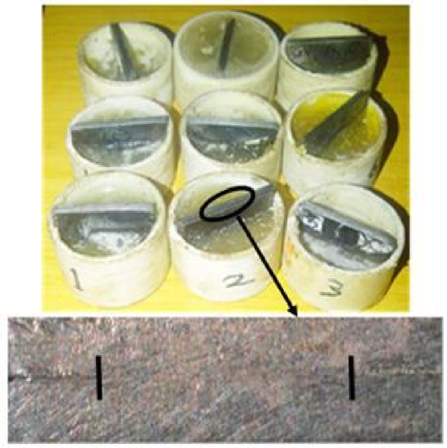

Figure 2. Picture of nugget diameter

Table 4. Experimental data for nugget diameter strength and S/N ratio

Current (kA)	Pressure (kPa)	Time (sec)	Nugget Dia (µm)	S/N Ratio
1	1	1	6800	76.6502
1	2	2	7000	77.0252
1	3	3	7210	77.2783
2	1	2	7500	77.5012
2	2	3	7700	77.7298
2	3	1	7800	77.9525
3	1	3	7900	78.0618
3	2	1	8200	78.1697
3	3	2	8620	78.8103

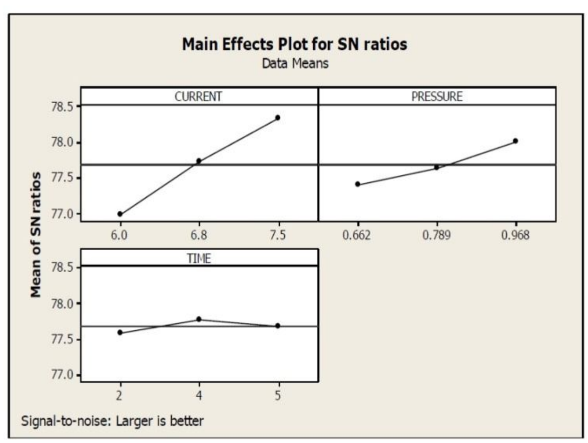

Figure 3. Main Effects plot for S/N ratio (nugget diameter)

Table 5. Response table for S/N ratio for nugget diameter

Level	Current (kA)	Pressure (kPa)	Weld Time (sec)
1	76.98	77.40	77.59
2	77.73	77.64	77.78
3	78.35	77.01	77.69
Delta	1.36	0.61	0.19
Rank	1	2	3

Figure 4. Resistance Spot Welding on Stainless steel type 304

Table 6. Analysis of Variance for SN ratios (nugget diameter)

CF	DOF	SS	MS	F ratio	P	%C
Current	2	2173622	1153144	128.2	0.008	80.82
Pressure	2	453089	147878	26.72	0.097	16.85
Time	2	45622	19144	2.69	0.452	1.70
ERROR	2	16956	8478			
TOTAL	8	2689289				

R-Sq=95.3%; R-Sq(adj)=81.1%; Significant at 95% confidence

IV. RESULTS AND DISCUSSIONS

The following conclusions could be drawn from the above investigation:

1. The response of S/N ratio with respect to tensile strength indicates the welding current to be the most significant parameter that controls the weld tensile strength where's the holding time and pressure are comparatively less significant in this regard.
2. The contribution of welding current holding time and pressure towards tensile strength is 61.1%, 28.7%and 4 % respectively as determined by the ANOVA method for tensile strength.

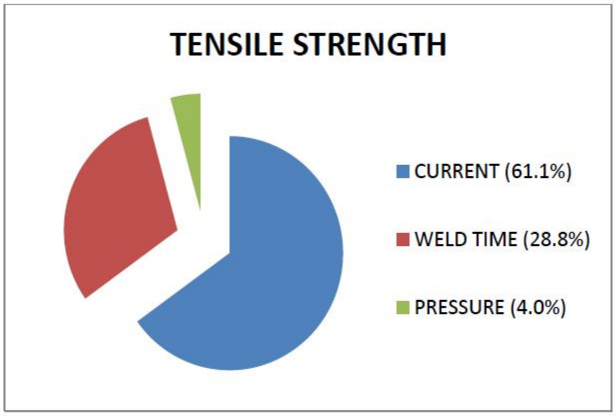

Figure 5. Contribution Pi diagram (Tensile Strength)

3. Optimum results have been obtain by taguchi method using medium current of 6.8 KA, medium pressure of 0.79KPa and high holding time of 5 seconds.
4. The response of S/N ratio with respect to nugget diameter also indicates the welding current to be the most significant parameter that controls the nugget diameter where's the pressure and welding time are comparatively less significant in this regard.
5. The contribution of welding current welding time and pressure towards nugget diameter is 80.82, 1.70 and 16.85 respectively as determined by the ANOVA method.

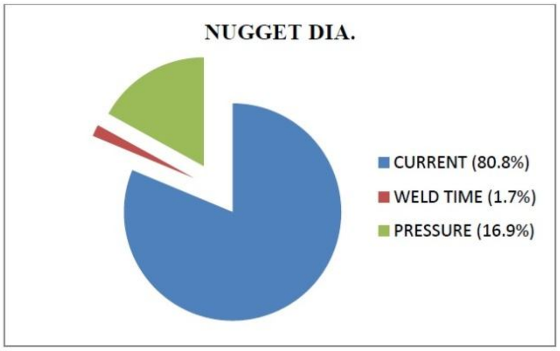

Figure 6. Contribution Pi Diagram (Nugget Diameter)

6. It follows the 80-20 rule of pareto principle [6]. The current contributes 80% the formation of nugget diameter although it is one of the important contributing factors.

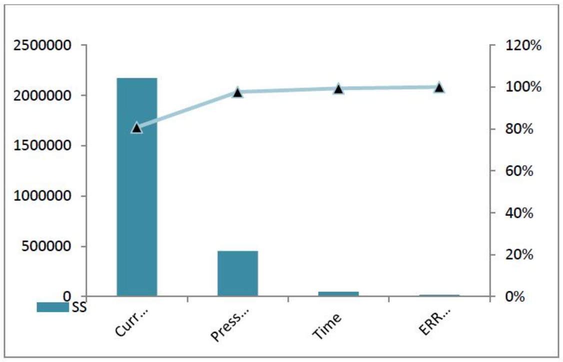

Figure 7. Pareto Chart of Contributing factors

7. Relationship graph could be plotted between the tensile strength and nugget diameter with parametric variations according to orthogonal array.

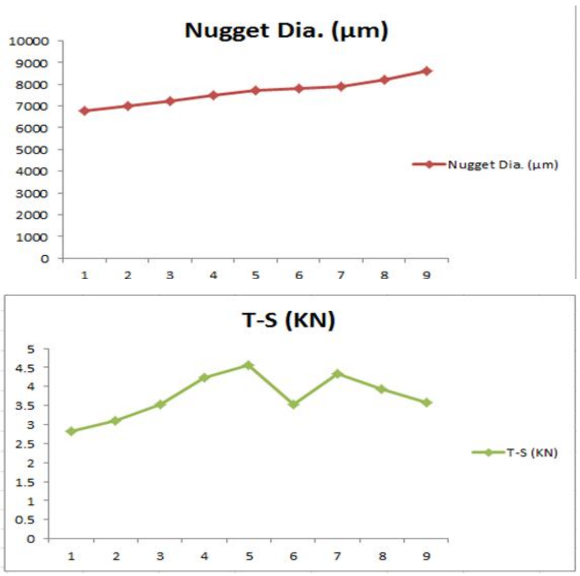

Figure 8. Comparison Graph between Tensile Strength and Nugget Diameter

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