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Study and Analysis of Various Parameters Affecting Nugget Formation in Resistance Spot Welding Using FEM

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Abstract*-In this project the effect of various parameters affecting the nugget formation in resistance spot welding is studied. Thus here we consider the material CRCA steel of grade EDD with specimen of dimension 110*30 and two upper and lower joining sheets having thickness 0.91mm and 1.22mm respectively and welding gun of integrated type with welding electrode of copper chromium having dome shape tip. And changing the parameters welding current, weld time and electrode force by keeping the other parameters constant for obtaining the optimum diameter of welding nugget. In this project Taguchi method is considered as a design of experiment in Minitab 17 software to obtain the effective parameters from the various parameters (here the Taguchi method of Minitab software reduces the 5^3 = 125 parameters are reduced to 25 effective parameters) then experimental work are carried on that effective parameters only. From that result one can predict the best combination of the parameters which can be validated with the experimental work. Similar parameters and boundary conditions of the best combination are applied to the FEA model of resistance spot welding and the analysis of that FEA model is carried out using the analysis APDL software. Then the nugget diameter obtained during the analysis of the FEA model of RSW is compared with the resulted nugget diameter obtained experimentally and with the predicted value of taguchi analysis.*

Keywords*-Nugget, spot welding, Weld time, Weld current, electrode force, taguchi, FEM Analysis, nugget diameter.*

I. INTRODUCTION

Welding is a fabrication or sculpture process that joins material, usually metal or thermoplastic by causing coalescence. This is often done by melting the work piece and adding a filler material to form a pool of molten material that cools to become a strong joint, with pressure sometimes used in conjunction with heat or by itself to produce the weld. In resistance welding the metal parts to be joined are heated to a plastic state over a limited area by their resistance to the flow of an electric current and mechanical pressure is used to complete the weld. In this process, preferably two copper electrodes are incorporated in a circuit of low resistance and the metals to be welded are pressed between the electrodes. The circuit is thus completed and the electrical resistance at the joint of the metals to be welded is so high, in comparison with the rest of circuit that if the current is heavy enough the highest temperature will be produced directly at the joint. The heat generated in the weld may be expressed by $H = I^2 RT$. To start the apparatus used for spot welding is often called a welding gun. It can be modified by the types of actuator used. There are mainly of two types of welding gun used the first is controlled by air pressure and will be referred to as an air gun. The second is used as a servo motor and will be referred to as a servo gun. The actuator, in either case, controls the position of, and force applied by the electrode tips. These are the parts of the welding apparatus that actually make contact with the material to be welded. They are typically made of copper, because of the high electrical and thermal conductivity. When the electrode contact the specimen there is a slight deformation of the electrode tip. This result in larger contact area between the tips and the specimen then would be found by simply measuring the electrode face diameter. This contact is referred to as the electrode diameter and is typically assumed to be circular. The force with which the electrode are pressed together is called as the electrode force. This force cause an area on the contacting surface of the specimen to be pressed very close together this area is called the contact diameter. The entire surface between the two specimens, where the weld form is called the faying surface. The welding current of 4–20 kA is used for making a single weld. The welding current depends on the material to be welded and work piece thickness. This may be used to weld steel and other metal parts up to a total thickness of 12mm. Several metallic materials with different thickness can be joined together by using spot welding. RSW provides mass production with easy automation and small number of employees.

II. DESIGN OF EXPERIMENT

2.1 Introduction:A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyzed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. DOE is a technique of defining and investing all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results.In a designed experiment, the engineer often makes deliberate changes in the input variables (or factors) and then determines how the output functional performance varies accordingly. It is important note that not all variables affect the performance in the same manner. Some may have strong influences on the output performance, some may have medium influences and some have no influence at all. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance in products.The design of experiment is used to develop a layout of the different conditions to be studied. An experiment design must satisfy two objectives; first, the number of trials must be determined; second, the conditions for each trial must be specified. Before designing an experiment, the knowledge of the product/process under their investigation is of prime importance for identifying the factors likely to influence the outcome.Thus Design of experiment (DOE) is a method to identify the important factors in a process, identify and fix the problem in a process, and also identify the possibility of estimating interactions.

2.2 Factors and Levels

Table 1: Factors and their Levels

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
Weld current (KA)	11	12	13	14	15
Weld time (cycles)	11	12	13	14	15
Electrode force (Kgf)	2	3	4	5	6

2.3Best 25 Combination as per taguchi analysis

Table 2: Orthogonal Array L25 of Taguchi Method using Minitab 17 Software

Experiment No.	Weld Current (KA)	Weld Time (cycles)	Electrode Force (Kgf)
1	11	11	2
2	11	12	3
3	11	13	4
4	11	14	5
5	11	15	6
6	12	11	3
7	12	12	4
8	12	13	5
9	12	14	6
10	12	15	2
11	13	11	4
12	13	12	5
13	13	13	6
14	13	14	2
15	13	15	3
16	14	11	5
17	14	12	6
18	14	13	2
19	14	14	3
20	14	15	4
21	15	11	6
22	15	12	2
23	15	13	3
24	15	14	4
25	15	15	5

III. EXPERIMENTAL SETUP

3.1 Basic Components of RSW

The below figure shows the arrangement of the experimental setup of resistance spot welding with its basic components.

- Parameter-controller
- Welding Gun.
- Suspension arm.
- Power supply
- Work piece
- Gun controller
- Work piece

3.2Properties of CRCA steel

Table 3: CRCA steel Properties

MATERIAL PROPERTIES OF CRCA								
Grade	Chemical composition % (max)				Mechanical property			
EDD	C	Mn	S	P	Tensile YieldMpa	Yield stress Mpa	Elongation% min	HardnessHR B
	0.08	0.40	0.30	0.30	270-350	150-200	45	50
ENGINEERING PROPERTIES								
Young's Modulus of elasticity: 200 * 10^6 at 20^oC								
Density: 7.87 g/cm^3								
Thermal Conductivity: 93 W/m^oc at 20^oC								
Specific heat: 481 J/kg/o_C in 50 to 100^o C								
Electrical Resistivity: 0.142 □Ωm at 20^oC								

3.3Experiment results

The dimension of the specimen taken for the practical and analysis study during the work is of 110*30 which is shown below with a 2D model created in PTC creo PRO-E.

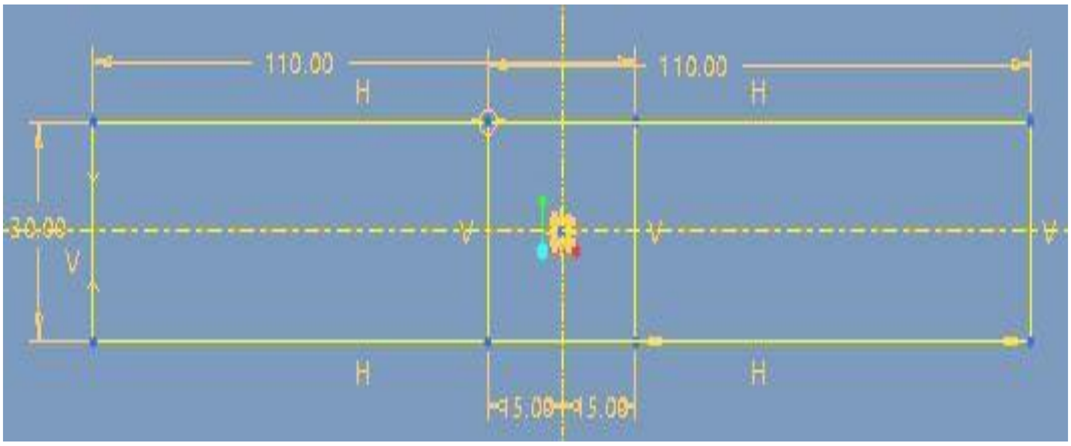

Fig 1: specimen dimension

The 25 Experiments are performed on the above specimen with different parameter combination obtain from taguchi analysis an the nugget diameter are obtain for each combination.

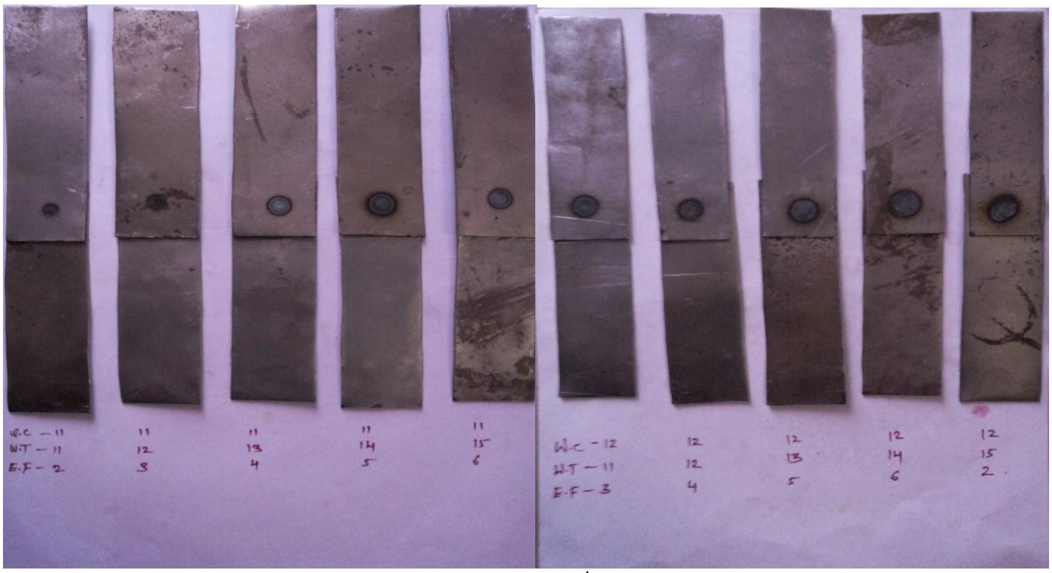

Fig 2: Spot weld for 1st 10 experiment

Table 4: Nugget diameter for 1 to 25 experiment with S/N ratio & Mean values

Experiment No.	Weld Current (KA)	Weld Time (cycles)	Electrode Force (Kgf)	Nugget Diameter (mm)	SNRA1	MEAN1
1	11	11	2	3.5	10.8814	3.5
2	11	12	3	3.6	11.1261	3.6
3	11	13	4	3.65	11.2459	3.65
4	11	14	5	3.85	11.7092	3.85
5	11	15	6	3.95	11.9319	3.95
6	12	11	3	4.5	13.0643	4.5
7	12	12	4	4.55	13.1602	4.55
8	12	13	5	4.75	13.5339	4.75
9	12	14	6	4.95	13.8921	4.95
10	12	15	2	5	13.9794	5
11	13	11	4	5.45	14.7279	5.45
12	13	12	5	5.6	14.9638	5.6
13	13	13	6	6	15.563	6
14	13	14	2	6.7	16.5215	6.7
15	13	15	3	6.85	16.7138	6.85
16	14	11	5	6.86	16.7265	6.86
17	14	12	6	6.9	16.777	6.9
18	14	13	2	6.95	16.8397	6.95
19	14	14	3	7.15	17.0861	7.15
20	14	15	4	7.45	17.4431	7.45
21	15	11	6	7.56	17.5704	7.56
22	15	12	2	7.85	17.8974	7.85
23	15	13	3	7.95	18.0073	7.95
24	15	14	4	8.1	18.1697	8.1
25	15	15	5	8.15	18.2232	8.15

Table 5: Response table for Signal to Noise Ratio for Nugget Diameter

LEVELS	WELD CURRENT (KA)	WELD TIME (Cycles)	ELECTRODE FORCE (Kgf)
1	11.38	14.59	15.22
2	13.53	14.78	15.20
3	15.70	15.04	14.95
4	16.97	15.48	15.03
5	17.97	15.66	15.15
Delta	6.59	1.06	0.27
Rank	1	2	3

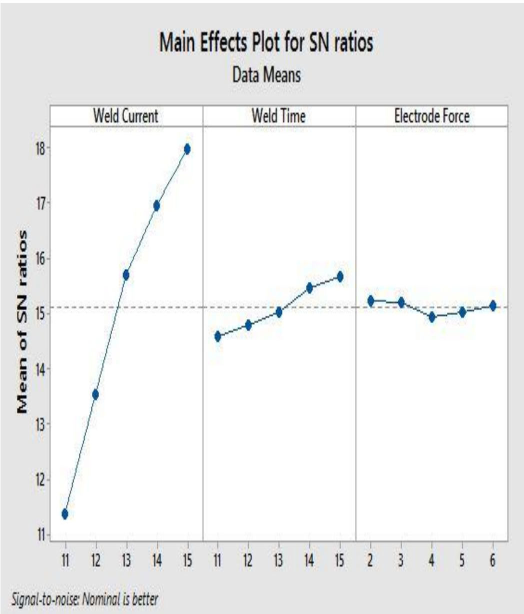

Fig 3: Main effect plot of Signal to Noise Ratio for Nugget Diameter

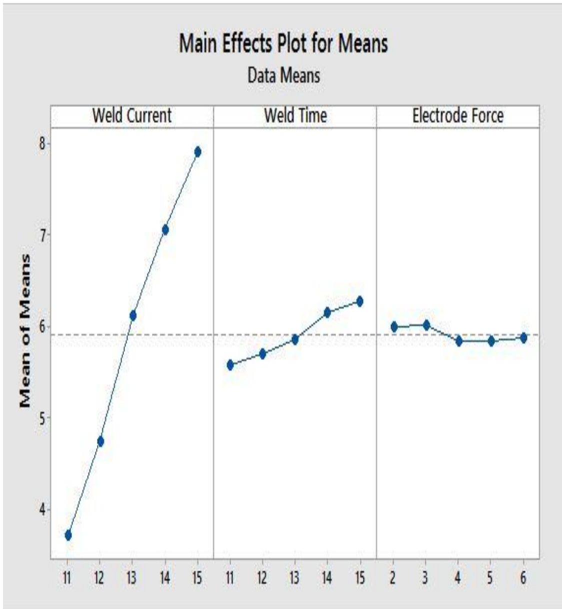

Fig 4: Main effect Plot of means for Nugget Diameter

Table 6: Response table of mean Ratio for Nugget Diameter

LEVELS	WELD CURRENT (KA)	WELD TIME (Cycles)	ELECTRODE FORCE (Kgf)
1	3.710	5.574	6.000
2	4.750	5.700	6.010
3	6.120	5.860	5.840
4	7.062	6.150	5.842
5	7.922	6.280	5.872
Delta	4.212	0.706	0.170
Rank	1	2	3

3.4 Predicted result from Minitab 17

Table 7: predicted value

Prediction value	
Weld current (kA)	13
Weld time (cycles)	13
Electrode force (kgf)	4
S/N Ratio	15.4650
Nugget diameter	5.33 mm

From the above taguchi analysis the best 25 combinations are obtained and on which 25 experiments are carried out and the different nugget diameters are obtained, then the best predicted values are obtained which will further satisfied with the practical as well as with the analysis work for the same predicted values are carried out. This predicted value is 5.33 mm. finally all the above results for the nugget diameter are compared among themselves.

IV. MODELING AND ANALYSIS

4.1 Modeling

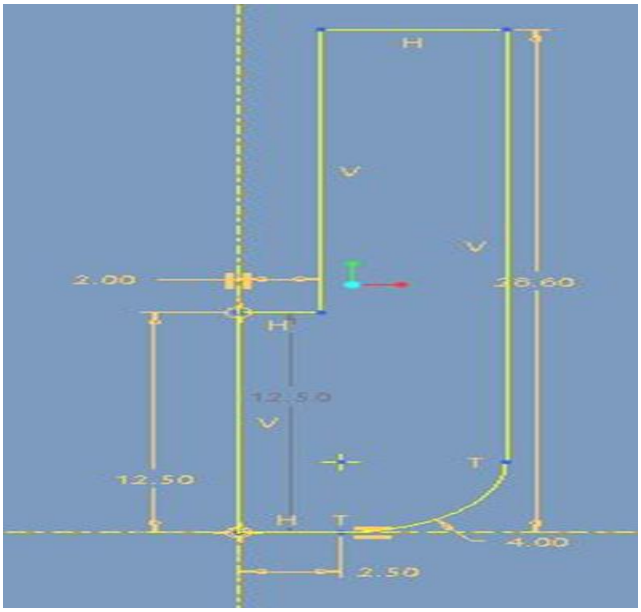

Fig 5: 2D Model of Electrode with dimension

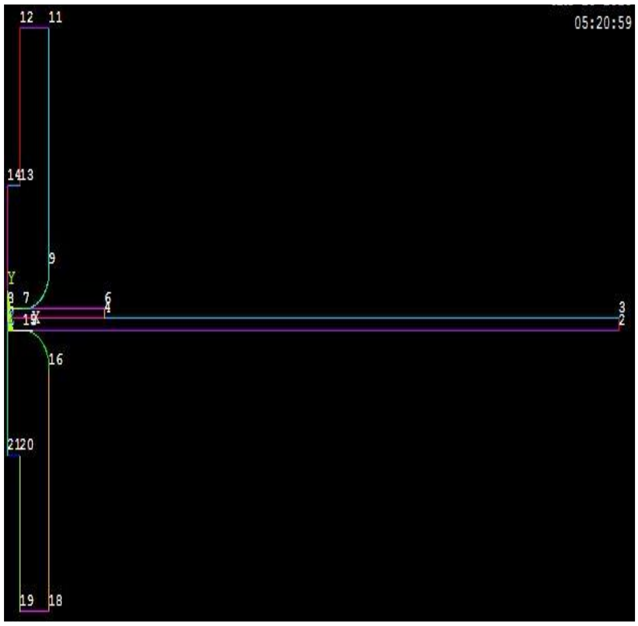

Fig 6: Wire frame model created with plotted coordinates

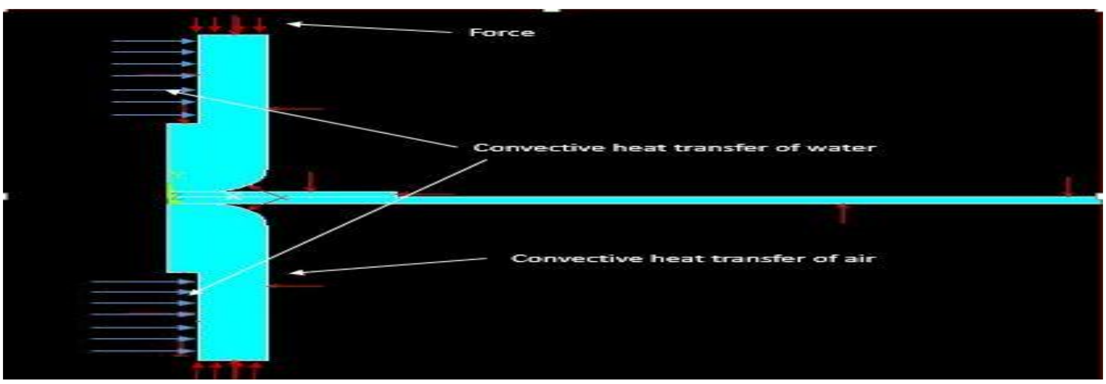

Fig 7: Applied load

4.2 Analysis on predicted value of taguchi

The coupled static-thermal analysis of half model is carried out because the model is symmetric about the axis so for simplicity of calculation it is taken half. Here PLANE55 element is selected having 4 node. Fig below shows the temperature profile and nugget growth at the time when nugget start to form. At the start of the welding process, the temperature at the center of faying surface increases very fast. The highest temperature remains at the center of the faying surface throughout the whole welding process. Melting first occur at the faying surface and then expand to the material near it. Due to the resistance offered to the flow of current at the faying surfaces, Joule heat is generated at this surfaces which is greater than the heat generated at other points on the weld surfaces. The nugget is formed having the welding process assuming 1530 ºC as the melting point of CRCA steel. The spot nugget region appears as red in color. The weld nugget is close to the elliptical shape. The highest temperature always remains in the middle of the work piece and the temperature away from the faying surface decreases due to transfer of heat by convection of air and cooling water. By changing the welding conditions, the temperature profile could be varied which in turn changes the nugget size i.e. the welding quality.

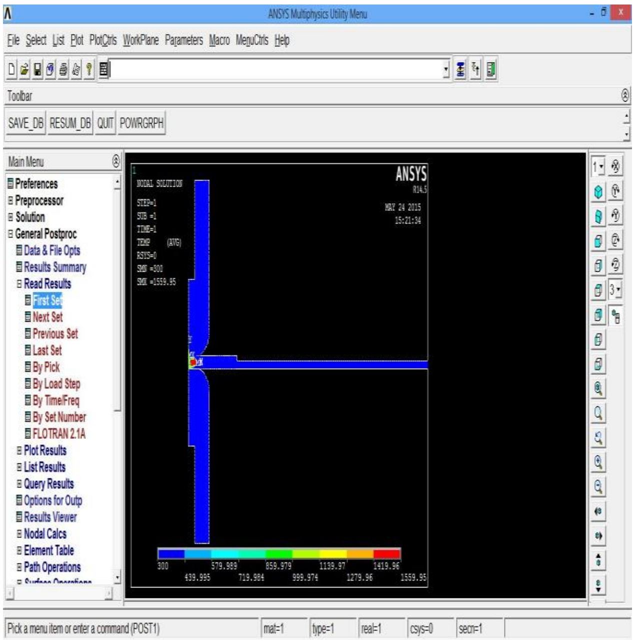

Fig 8: HAZ in ansys

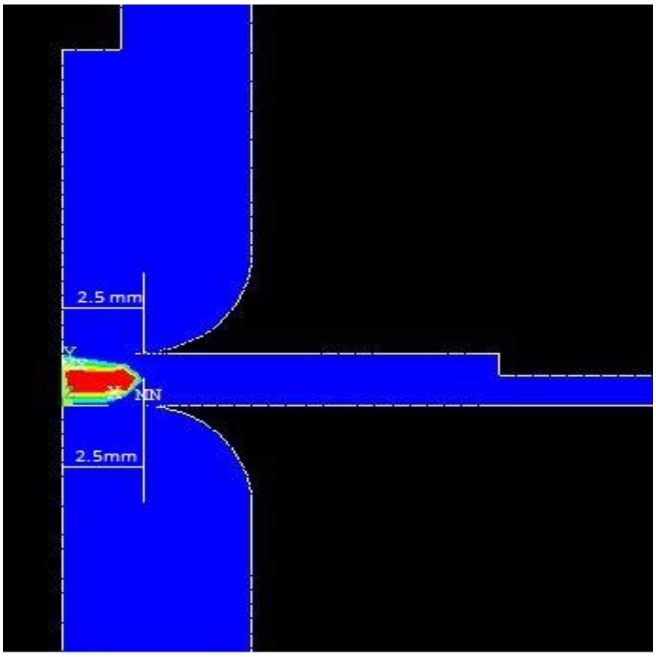

Fig: 9 Nugget diameter

Table 8 Nugget diameter from analysis

Analysis value	
Weld current	13
Weld time	13
Electrode force	4
Nugget diameter	5 mm

From the above analysis 5 mm nugget diameter is obtained by placing the load of the above values for each parameters.

4.3 Practical onpredicted value of taguchi

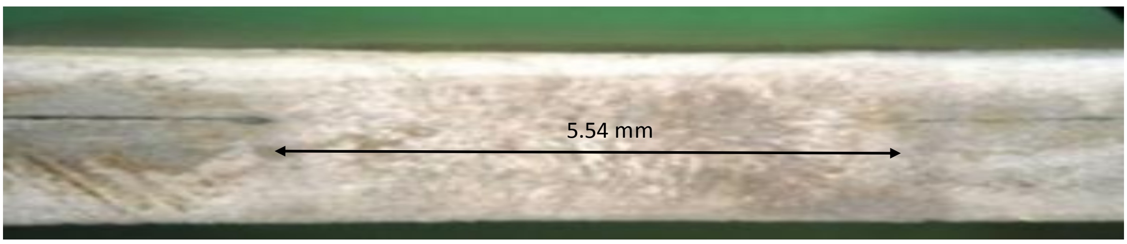

Fig: 10 Practically validated Nugget diameter

Experimental value	
Weld current	13
Weld time	13
Electrode force	4
Nugget diameter	5.54 mm

Table 9 nugget diameter obtain practically for the predicted value

V. Result and discussion

5.1 Comparison of practical value with Predicted and analysis value

In this study the nugget diameter obtain from the predicted value of taguchi analysis in minitab 17 and by finite element analysis is validated with the experimental result of nugget diameter with same parameters and their results obtained is compared with the below comparison table.

Table 10 Comparison table of nugget diameter

Sr No.	Parameters	Taguchi predicted Diameter	Analysis obtain diameter	Experimental result Diameter
1	Weld current	5.33	5	5.54
2	Weld time			
3	Electrode force			

VI. Conclusion

The aim of this study is to study the effect of welding parameters, weld current weld time and electrode force on nugget diameter. Here the 125 experiments are reduced to 25 experiments and the best predicted value of welding parameters for the nugget diameter is obtained by using taguchi analysis from the minitab 17 software. The same nugget diameter is obtained with the finite element analysis for same parameters using ansys APDL software and both the result obtain are validated with the practical work with same nugget diameter. As a result the prediction of best nugget diameter with there parameters can be easily predicted with FEA.

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