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INVESTIGATION OF THE EFFECT OF CURRENT ON TENSILE STRENGTH AND NUGGET DIAMETER OF SPOT WELDS MADE ON AISI-1008 STEEL SHEETS

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Abstract—**The results of the investigation indicate the welding current to be the most significant parameter controlling the weld tensile strength as well as the nugget diameter. The contribution of welding current holding time and pressure to tensile strength are 61%, 29%, 4% respectively and the contribution of these parameters to nugget diameter are 81%, 17%, 1.7% respectively. Relationship graph have been plotted between tensile strength and nugget diameter with parametric variations according to orthogonal array**

Keywords— **resistance spot welding, taguchi method, tensile strength, nugget diameter, annova etc**

I. INTRODUCTION

Resistance spot welding (RSW) is a major sheet metal joining process in many industries, such as the automobile, domestic appliances, air craft and space craft fabrications. It is an efficient joining process widely used for the fabrication of sheet metal assemblies. There are 3000-6000 spot welds in any car, which shows the level importance of the resistance spot welding. RSW has excellent techno-economic benefits such as low cost, high production rate and adaptability for automation which make it an attractive choice for auto-body assemblies, truck cabins, rail vehicles and home appliances. [1] It is one of the oldest of the electric welding processes in use by industry today. Furthermore, other metal-to-metal connections, such as wire-to-wire joints in the electronics industry, are accomplished by resistance spot welding. Application-specific measures, such as the diameter of the welding spot, determine the quality of the joint. The weld is made by a combination of heat, pressure, and time. As the name implies, it uses the resistance of the materials to the flow of current that causes localized heating between the part to be joined. Understanding of physical mechanisms for easily manipulating and controlling weld qualities in advance is important.[2]

II. TAGUCHI METHOD

It is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost [3]. Taguchi method can be efficiently used for designing a system that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of strategically designed experiments. Taguchi approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained wide popularity in the engineering and scientific community [4-5]. The desired welding parameters are determined based on experience & books.

Steps of Taguchi method are as follows:

1. Identification of the main function, to be optimized and its side effects and failure mode.
2. Identification of noise factors, testing conditions and quality characteristics.
3. Identification of the main function to be optimized.
4. Identification the control factors and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analyzing the data and prediction of the optimum level.
8. Determining the contribution of the parameters on the performance.
9. Performing the verification experiment and planning the future action. [6]

This study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes can be taken into account at the design stage [7]. Although similar to design of experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore saving costs and increasing profit. Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach: system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design.

The objective of the design [8] is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values using the optimal process parameters.

The parameter design is the key step in the Taguchi method for achieving high quality without increasing cost. The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum conditions; and conducting confirmation runs using the optimal levels of the parameters. The main effects indicate the general trend of influence of each parameter. Knowledge of the contribution of individual parameters is the key for deciding the nature of the control to be exercised on a production process.[9]

Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence [10]. Taguchi suggests two different routes for carrying out the complete analysis. In the standard approach the results of a single run or the average of the repetitive runs are processed through the main effect and ANOVA . The second approach, which Taguchi strongly recommends for multiple runs, is to use the signal-to-noise (S/N) ratio for the same steps in the analysis.[11]

III. Resistance Welding Parameters

There are three main parameters which control the quality of resistance spot welding. Diagrammatically shown in figure:

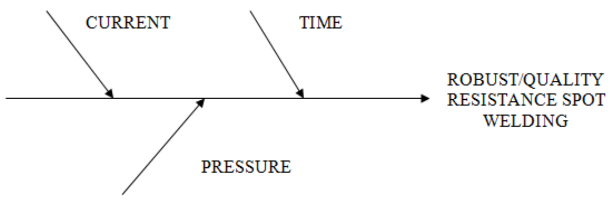


Figure.1 Cause and effect diagram of main welding parameters

A. Effect of Welding Current

Current controls the heat which generated according to the equation Q = I2Rt.this shows that the current has more influence on the amount of heat generated

Tensile shear strength increases rapidly with increasing current density. Excessive current density will cause molten metal expulsion (resulting in internal voids), weld cracking, and lower mechanical strength properties. Typical variations in shear strength of spot welds as a function of current magnitude are shown in Figure 2. In the case of spot welding excessive current will overheat the base metal and result in deep indentations in the parts and, it will cause overheating and rapid deterioration of the electrodes.

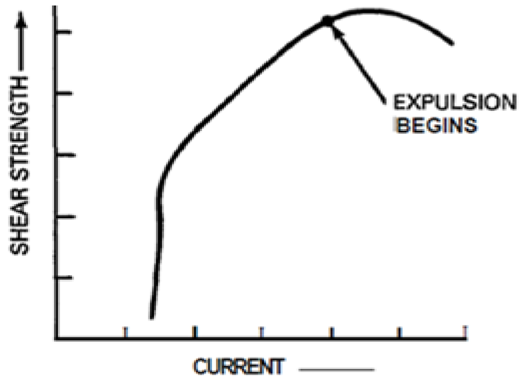


Figure.2 Effect of welding current on shear strength

B. Effect of Weld Time

The rate of heat generation must be such that welds with adequate strength will be produced without excessive electrode heating and rapid deterioration. The total heat developed is proportional to weld time. During a spot welding operation, some minimum time is required to reach melting temperature at some suitable current density. Excessively long weld time will have the same effect as excessive amperage on the base metal and electrodes. Furthermore, the weld heat-affected zone will extend farther into the base metal.

The relationship between weld time and spot weld shear strength is shown in Figure.3 assuming all other conditions remain constant. To a certain extent, weld time and amperage may be complementary. The total heat may be changed by adjusting either the amperage or the weld time. Heat transfer is a function of time and the development of the proper nugget size requires a minimum length of time, regardless of amperage

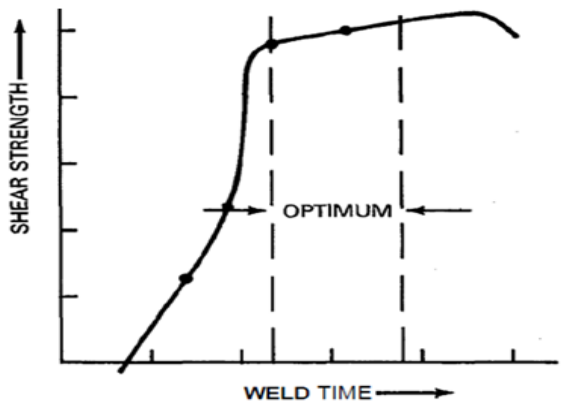


Figure.3 Tensile-shear strength as a function of weld time

C. Effect of Welding Pressure

Welding pressure is produced by the force exerted on the joint by the electrodes. Electrode force is considered to be the net dynamic force of the electrodes upon the work, and it is the resultant pressure produced by this force that affects the contact resistance. As the pressure is increased, the contact resistance and the heat generated at the interface will decrease. To increase the heat to the previous level, amperage or weld time must be increased to compensate for the reduced resistance. The surfaces of metal components, on a microscopic scale, are a series of peaks and valleys. When they are subjected to light pressure, the actual metal-to-metal contact will be only at the contacting peaks, a small percentage of the area. Contact resistance will be high. As the pressure is increased, the high spots are depressed and the actual metal-to-metal contact area is increased, thus decreasing the contact resistance. [12]

IV. Weld Quality Attributes

The quality of a weld is usually expressed by its measurable features, such as the physical attributes and the various strengths, when inspected in either a destructive or nondestructive manner. A weld's quality can be described in three ways: by its physical or geometric features, its strength or performance, or the process characteristics during welding.

The geometric features are either directly visible after a weldment is made or revealed through destructive tests, such as peeling or cross-sectioning or seeing the microstructures, or nondestructive tests using, for example, ultrasonic or x-ray devices.

The commonly used weld attributes are:

- Nugget/button size
- Penetration
- Indentation
- Cracks (surface and internal)
- Porosity/voids
- Sheet separation
- Surface appearance

Among these weld attributes, weld size, in terms of nugget width or weld button diameter, is the most frequently measured and most meaningful in determining a weld's strength. When two sheets are joined by a weld at the nugget, its size determines the area of fusion and its load-bearing capability. However, the nugget/weld size alone is often insufficient in describing a weld's quality, as it does not necessarily imply the structural integrity of the weld. Other features of a weld, such as penetration, may complement the nugget size and provide useful information on the degree of adhesion. Weld and nugget are considered interchangeability by many, especially in oral presentations. Although closely related, however, they are not the same by definition or measurement. In fact, a weld is meant to contain all parts of a weldment, such as the heat-affected zone (HAZ), in addition to the nugget. Confusion is also in the use of button diameter or nugget diameter. As a nugget and its size are usually revealed by cross sectioning for metallo graphic examination, a nugget is exposed for measuring its width, not diameter, as shown in Figure 1 The figure also shows other features that can be revealed by cross-sectioning a weldment.[13]

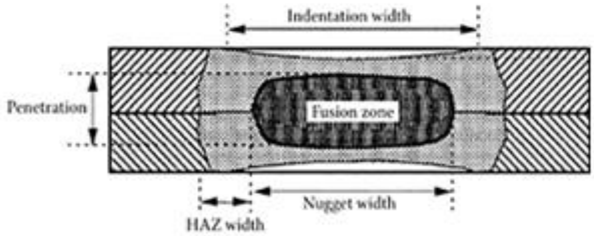


Figure.4 Weld attributes revealed by metallographic sectioning

V. Method Of Experiment

The three main parameters in spot welding are current, contact resistance and weld time. In order to produce good quality weld the above parameters must be controlled properly. The amount of heat generated in this process is governed by the formula: $Q = I^2 R T$

Where Q = heat generated, Joules
I = current, Amperes
R = resistance of the work piece, Ohms
T = time of current flow, second

A. Selection Of Metal

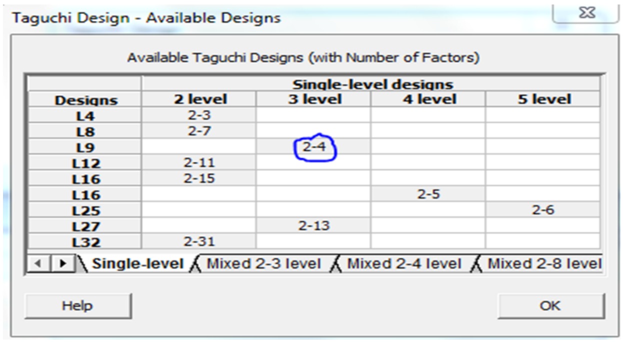
Firstly I will select the metal to be weld according desire weldability which must rely on basic properties of the material, such as strength, corrosion or erosion resistance, ductility, and toughness. The properties of the various metallurgical structures associated with the thermal cycles encountered in the welding operation must also be included in the design process.

Material Detail:

Material used is low carbon cold rolled 0.9 mm mild steel sheets (AISI 1008/ASTM A366) with the following composition carbon 0.08%; manganese 0.6%;phosphorus 0.35%; copper 0.2% ;sulphur 0.04% remaining iron.

B. Design The Orthogonal Array

Depending upon number of levels in a factor, a 2 or a 3 level OA can be selected. If some factors are two-level and some are three-level, then whichever is predominant would indicate which kind of OA is to be selected. Once the decision is made about the right OA, then the number of trials for that array would provide the adequate total dof, When required dof fall between the two dof provided by two OAs, the next larger OA must be chosen.


Taguchi Design - Available Designs

Available Taguchi Designs (with Number of Factors)

Designs	2 level	3 level	4 level	5 level
	Single-level designs			
L4	2-3			
L8	2-7			
L9		2-4		
L12	2-11			
L16	2-15			
L16			2-5	
L25				2-6
L27		2-13		
L32	2-31			

Single-level / Mixed 2-3 level / Mixed 2-4 level / Mixed 2-8 level

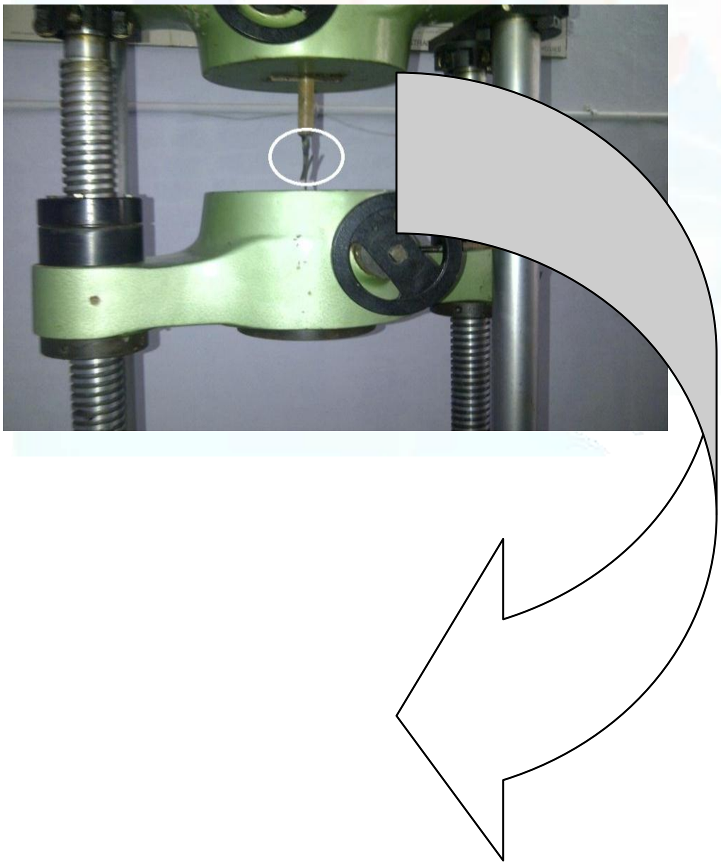
Help OK

Figure.5 selection of taguchi design

VI. Experimental Procedure

The results have been recorded as shown in (Tabl1.1) and analysis the tensile strength of the welded specimen.

Figure.6 Welded specimen



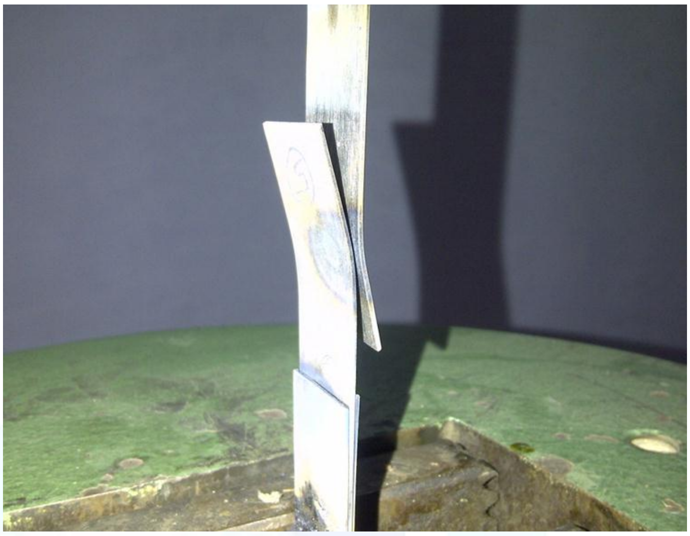


Figure.7 Tensile strength testing

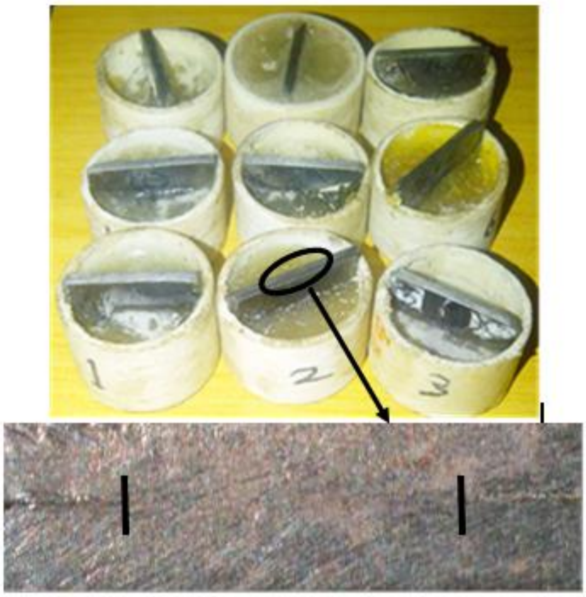


Figure.8 Arrangement for microscope view and one of microscopic image for measuring the nugget diameter

1) Analysis Of S/N Ratio Based On Taguchi Method

Taguchi recommends analyzing data using the S/N ratio that will offer two advantages; it provides guidance for selection the optimum level based on least variation around on the average value, which closest to target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target. The experimental results are analyzed to investigate the main effects.

According to Taguchi method, S/N ratio is the ratio of "Signal" representing desirable value, i.e. mean of output characteristics and the "noise" representing the undesirable value i.e., squared deviation of the output characteristics. It is denoted by η and the unit is dB. The S/N ratio is used to

measure quality characteristic and it is also used to measure significant welding parameters.
According to quality engineering the characteristics are classified as Higher the best (HB) and lower the best (LB). HB includes T-S strength and Nugget diameter which desires higher values. Similarly LB includes Heat Affected Zone (HAZ) for which lower value is preferred.

The summary statistics the S/N ratio η (dB) is given by:

$$\eta = -10\ log\frac{1}{N}\sum_{i=1}^{n}\frac{1}{y^2}$$

Larger the best performance

$$\eta = -10\ log\frac{1}{N}\sum_{i=1}^{n}y^2$$

Lower the best performance

TABLE 1 Process parameters with their values at three levels

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

TABLE 2 Experimental data for tensile shear (T-S) strength and S/N ratio

C	**P**	**T**	**T-S (KN)**	**Nugget Dia. (μm)**	**S/N Ratio.1**	**S/N Ratio.2**
1	1	1	2.82	6800	9.0050	76.6502
1	2	2	3.10	7000	9.8272	77.0252
1	3	3	3.54	7210	10.9801	77.2783
2	1	2	4.23	7500	12.5268	77.5012
2	2	3	4.55	7700	13.1602	77.7298
2	3	1	3.54	7800	10.9801	77.9525
3	1	3	4.33	7900	12.7298	78.0618
3	2	1	3.94	8200	11.9099	78.1697
3	3	2	3.58	8620	11.0777	78.8103

Where C is current P is pressure and T is time.

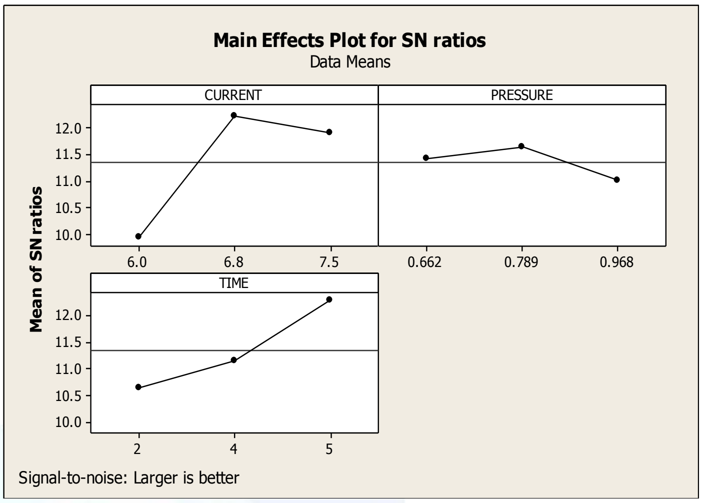


Figure.9 Main Effect Plot For S/N Ratio (Tensile Strength)

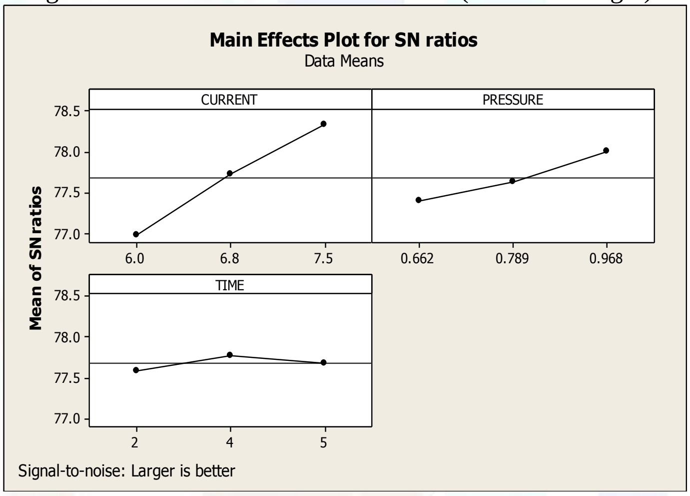


Figure.10 Main Effect Plot For S/N Ratio (nugget diameter)

TABLE 3 Response table for S/N ratio for T-S strength

Level	**Current**	**Pressure**	**Weld time**
1	9.937	11.421	10.632
2	12.222	11.632	11.144
3	11.906	11.013	12.290
Delta	2.285	0.620	1.658
Rank	1	3	2

TABLE 4 Response table for S/N ratio for nugget diameter

Level	**Current**	**Pressure**	**Weld time**
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

VII. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels.

TABLE-5 Analysis of Variance for SN ratios(tensile strength)

CF	**DOF**	**SS**	**MS**	**F RATIO**	**P**	**% C**
Current	2	9.1956	4.5978	9.92	0.092	61.11
Pressure	2	0.5956	0.2978	0.64	0.609	3.96
Time	2	4.3261	2.1631	4.67	0.177	28.76
ERROR	2	0.9273	0.4637			
TOTAL	8	15.0446				

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

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

VIII. CONCLUSION

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%, 28.7%and 4% respectively as determined by the ANOVA method for 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, 16.85 and 1.70**respectively as determined by the ANOVA method

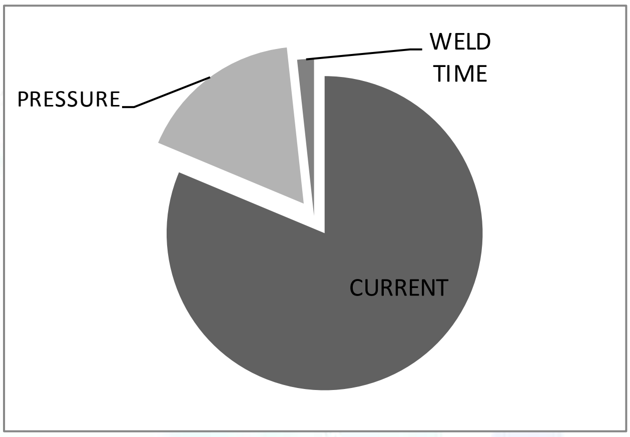


Figure.11 Contribution Pi Diagram

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

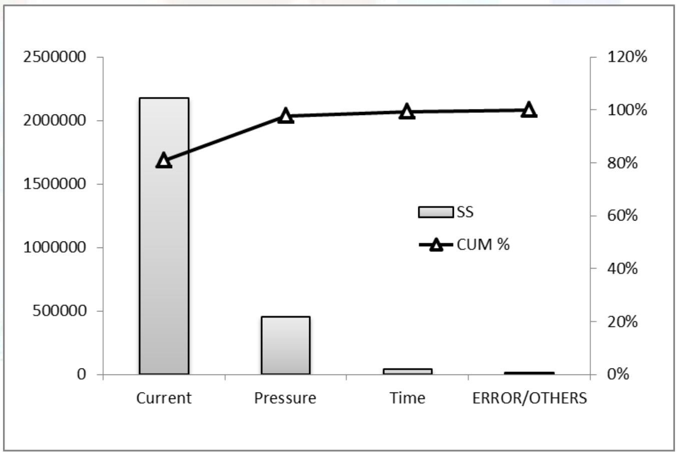
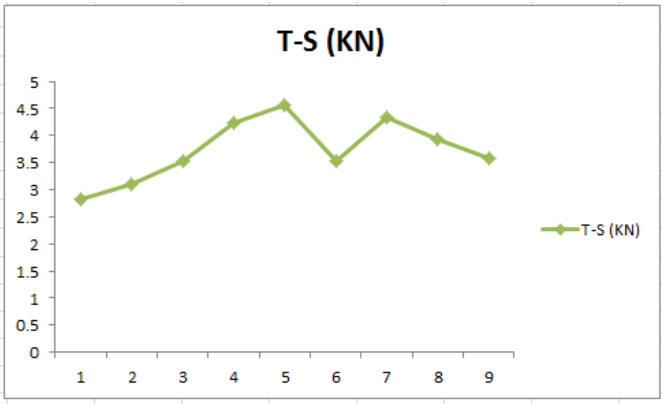


Figure.12 pareto chart of contributing factors

7. Relationship graph could be ploted between the tensile strength and nugget diameter with parametric variations according tp orthogonal array(figure.13)



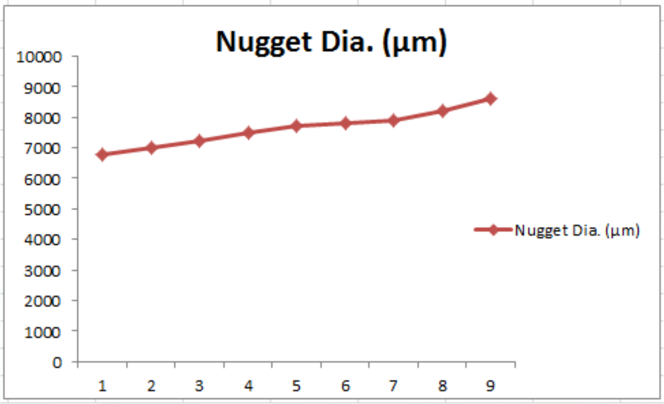


Figure. 13 Comparision graph between tensile strength and nugget diameter

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