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# Process Parameters Effect of Resistance Spot Welding on Weld Quality

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***Abstract*:** Resistance Spot Welding is a process of joining the sheet metal parts. In this study spot welding machine is used to weld the pads on a pan of the fuel tank. Material used in fuel tank's pan and pad is Cold Reduced Low Carbon Steel Sheet. The thickness for pad is 1.50 mm and for pan is 0.80 mm (Galvanized). The diameter of electrode used for spot welding is 5mm. There is a rejection of fuel tank due to low weld tensile strength. So, DMAIC (Define, Measure, Analyse, Improve & Control) method and Taguchi Method is used for reduction in rejection level. Experiment is carried out on Resistance Spot Welding machine. The highly effective parameters as welding current and weld cycle time with their different levels are used. These parameters are affecting the quality of resistance spot welding in terms of tensile strength, nugget size and internal defect. Each parameter has its effect on output quality parameter. The purpose of this study is to find out the effect of two control parameters like welding current and weld cycle time of resistance spot welding machine on tensile strength, nugget size and internal defect of the spot welding as a weld quality. Ultrasonic Flaw Detection Test as a Non-Destructive test and Tensile Test as a Destructive test is used. Optimization of welding current and cycle time by using software is used for reduction in rejection level.

***Keywords: Resistance Spot Welding (RSW), Weld Quality, Tensile Strength, DMAIC, Taguchi Method***

## I. Introduction

As per the requirement of different products, welding engineering has gone through a rapid development to meet the market demand. There is a high demand of products for high strength to weight ratio. Resistance Spot Welding is widely used for the fabrication of plain as well as galvanized sheet metals.RSW has techno-economical benefits such as low cost, high speed, cleanliness and simultaneously suitability for automation. It is widely used for fabrication of automotive chassis, home appliances, and rail vehicles. There are 3000-7000 spot welds in car-body fabrication which require very precise process control. The weldability of galvanized steel sheet is required more attention than that of ordinary steel sheets due to spatter and electrode pollution during the spot welding.

Resistance spot welding quality is influenced by process parameters and output parameters. Input parameters are welding current, resistance, time, electrode force, cooling water flow, electrode shape, sheet metal surface condition, etc. while the output parameters are tensile-shear strength, surface appearance, corrosion resistance, nugget size, internal defects, etc. The RSW process output is affected by metallurgy of base metal, Heat Affected Zone (HAZ), nugget. It is also affected by weldability of sheet metal, mechanical and thermal stresses induced due to rapid heating and cooling.

## II. Literature Review

Moshayedi Hessamoddin, Sattari-Far Irjad [1] found that Welding Current is more effective on nugget size as compared to other factors.

Singh Hartaj, Pandita Neeraj, Singh Pradeep, Singh Kapil [2] investigated that by using DMAIC method the rejection level is reduced by using root cause analysis as well as corrective and preventive measures.

Zhao Dawei, Wang Yuanxun, Lin Zongguo, Sheng Suning [3] concluded that voltage- current curve during welding process is helpful for weld quality monitoring purposes.

Neugebauer R., Wiener T., Zosch A [4] investigated that resistance characteristics have effect on formation of weld nugget size.

Pandey A.K., Khan M.I., Moeed K.M [5] found that welding current is the most significant and optimum results have been found out by Taguchi Method.

Sahota D.S., Singh Ramandeep, Sharma Rajesh, Singh Harpreet [6] concluded that by increasing weld current and weld time results in an increase in weld nugget size.

Li YongBing, Wei ZeYu, Li YaTing, Shen Qi, Lin ZhongQin [7] found that electrode cone angle affects on nugget quality of resistance spot welding.

Pingili Rajanarender Reddy [8] found that Different types of electrode shapes affect nugget quality in resistance spot welding process.

Singh Niranjan Kumar Mr., Vijaykumar Y. Dr. [9] found that Validation of Taguchi method for optimizing the process parameters in resistance spot welding.

Hamidinejad S.M., Kolahan F., Kokabi A.H. [10] concluded that there is a non-linear relationship between the welding parameters as well as the tensile-shear strength of the RSW joints.

Thakur A.G., Rao T.E., Mukhedkar M.S., Nandedkar V.M. [11] investigated that the highly effective parameters on tensile shear strength were found as welding current and welding time.

Yi Luo, Jinhe Liu, Huibin Xu, Chengzhi Xiong, Lin Liu [12] found that the effects of welding process on nugget size and mechanical properties are varying with non-linear characteristics.

Martin Oscar, Tiedra Pilar De, Lopez Manuel, San-Juan Manuel, Garcia Cristina, Martin Fernando [13] concluded that Tensile Shear Load Bearing Capacity (TSLBC) increases with increasing Welding Time (WT) and Welding Current (WC) up to a particular values then it decreases.

Karci Feramuz, Kacar Ramazan, Gunduz Suleyman [14] found that Grain growth occurred in heat affected zone (HAZ) adjacent to the weld nugget has effect on weld failure.

Ozyurek Dursun [15] found that The heat input addition with increase in current caused coarsening of the microstructure of weld nugget as well as heat affected zone (HAZ).

Aslanlar S., Ogur A., Ozsarac U., Ilhan E. [16] investigated that optimization of welding current and weld cycle time for obtaining maximum tensile-shear strength value of galvanized chromate steel sheets' resistance spot welding.

Esme Ugur [17] found that the highly effective parameter on the tensile strength was found as welding current.

Bouyousfi B., Sahraoui T., Guessasma S., Tahar Chaouch K. [18] found that micro hardness and tensile test results show that the weld resistance is important.

Aslanlar S., Ogur A., Ozsarac U., Ilhan E., Demir Z. [19] investigated that maximum tensile-peel strength is obtained by optimizing weld current and weld cycle time.

Vural M., Akkus A., Eryurek B. [20] found that the endurance limit of the similar steel sheet combination is higher than that of different steel sheet combinations due to heat unbalance.

Aslanlar S. [21] investigated that optimization of weld current and weld cycle time is required for high surface quality and high tensile-shear and tensile-peel strength.

Vural Murat, Akkus Ahmet [22] concluded that Increase in the nugget diameter increases tensile-shear strength.

Jou Min [23] found that Heat input affects the nugget size.

## III. III. DMAIC METHODOLOGY

*(A) Define Phase Overview*

The primary aim of this phase is to identify, within each sub-process, the possibilities for defects or quality problems which can be arrived at through the use of different statistical tools. Whatever forms a quality problem takes – the DMAIC methodology is used to translate it into measurable form.

*Define the problem*

Developing a good problem statement helps to study the right variables. Each fuel tank G2's one pan has four pads on it periphery for outcome of strengthening of fuel tank G2 during its utilization. Due to more numbers of spot welds are to be made on fuel tank pan, resistance spot welding machine is used. Resistance Spot Welding is carried out on Cold Reduced Low Carbon Steel sheets Grade D - one sheet of 0.8mm for pan with galvanization and the other sheet of 1.5mm for pad without galvanization.

The work piece of fuel tank G2's one pan which is to be used for experiment is as shown in Fig.1. There is a rejection level of the fuel tank due to the low weld tensile strength. So, to reduce the rejection level and improving the present sigma level it is planned to implement a strategy for finding the root cause of the problem and effective solution and its implementation. After implementation of the solution, there is a requirement for consistency as well as continuous improvement of the sigma level. The material specification of given fuel tank G2 is shown in Table 1.

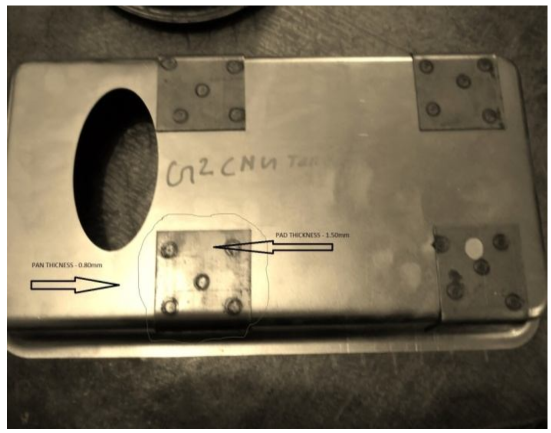


Fig. 1. One pan of fuel tank G2- work piece

Table. 1. Work piece material specification

| Sr. No. | Work piece material specification | |
|---|---|---|
| 1 | Material | Cold Reduced Low Carbon Steel |
| 2 | Grade | D |
| 3 | Hardness Number | 65 HRB |
| 4 | Thickness of pan | 0.8 mm(Galvanized) |
| 5 | Thickness of pad | 1.5 mm |
| 6 | Chemical Composition | C – 0.12%<br>Mn – 0.50%<br>S – 0.035%<br>P – 0.040% |

*Activities carried out for defining the problem*

(1) Brainstorming is a technique used to gather multiple ideas about the given problem. These ideas may primarily be concerned with diagnosing the causes of given problem and/or ways of tackling it. Every member involved in problem gets a turn to suggest his idea.
(2) Voice of Customer is taken into consideration by rejection level.

(3) Major noticeable defect is separation of pad from pan due to low tensile weld strength.

*Problem Definition*

"Resistance Spot Weld Tensile Strength is required to be increased for reduction in current rejection level."

*(B) Measure Phase Overview*

It is used to identify and rank the improvement opportunities. Critical to Quality (CTQ) characteristics of the process are identified for focusing on those areas which have the greatest impact on customer satisfaction.

*Data collection plan*

Here in this problem, attribute data as a number of defective fuel tanks G2 is measured by counts. There is a rejection of the fuel tank G2 due to the low weld tensile strength.

. The data base are taken into consideration from month August – 2014 to March – 2015.

*Calculation of DPMO (Defects per million opportunities)*

Here in parts per million is defined as a measure that takes into account the relative proportions of defects.

The equation to calculate parts per million is:

ppm = (Defectives/ Total parts) x 1,000,000

So, for month August – 2014, there is a value of defectives is 4 and value of total parts is 26.

Now, ppm for August – 2014 is given by,

ppm = (Defectives/ Total parts) x 1,000,000
= (4/26) x1, 000,000
= 153846

And its sigma level is 2.52.

*Database after measure phase for analysis purpose*

After careful consideration and proper calculation the database for the given problem with defects per million opportunities, sigma level and rejection cost month wise is as shown in table 2.

Table. 2. Fuel – tank G2's month wise DPMO, Sigma Level and Rejection Cost

| Month | Reject fuel Tank G2 | Total Tank G2 | DPMO | Sigma Level | Rejection Cost @Rs.550/- |
|---|---|---|---|---|---|
| Aug-14 | 4 | 26 | 153846 | 2.52 | 2200 |
| Sept-14 | 4 | 27 | 148148 | 2.54 | 2200 |
| Oct -14 | 5 | 30 | 166667 | 2.47 | 2750 |
| Nov-14 | 4 | 25 | 160000 | 2.49 | 2200 |
| Dec-14 | 6 | 35 | 171429 | 2.45 | 3300 |
| Jan -15 | 5 | 28 | 178571 | 2.42 | 2750 |
| Feb -15 | 4 | 25 | 160000 | 2.49 | 2200 |
| March-15 | 4 | 29 | 137931 | 2.59 | 2200 |
| SUM | 36 | 225 | 160000 | 2.49 | 19800 |

*(C) Analyse Phase Overview*

In this stage, at which new goals are set and the route maps created for closing the gap between current and target performance levels. Here analysis of the process is carried out to improve the sigma level of present process. The aim is to identify what causes the defects in each sub-process so that they can be rectified, either by redesigning the product or re-engineering the process.

*Analyse Phase for Problem*

The fundamental question that needs to be answered in the analyze phase is, "What are the critical root causes?" Root causes are determined from the baseline of performance.

*Cause and Effect Diagram*

The cause and effect diagram is also known as the fishbone or Ishikawa diagram, is a structured brainstorming tool. The tool is functionally used to generate balanced ideas of potential root causes.

The cause and effect diagram for the given problem related to rejection of fuel tank G2 is as shown in Fig.2.

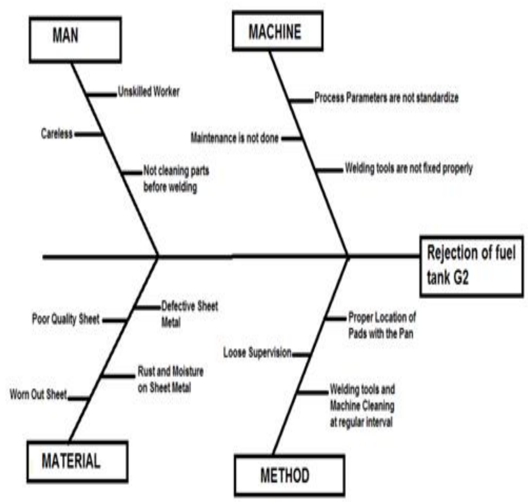


Fig. 2. Cause and Effect diagram for fuel tank G2

*Why – Why Analysis*

Why – Why technique is used to dig out several out of which one may be the root cause of the problem under consideration.

Root cause analysis is intended to ensure that we solve the right problem and we get to the root of what is actually causing the problem.

For this problem, why-Why Analysis is carried out which is mentioned below.

Problem Statement: - Resistance Spot Weld Tensile Strength is required to be increased for reduction in current rejection level.

**Why?**

The tensile Strength of Spot Weld depends upon its weld nugget diameter.

**Why?**

The nugget diameter is dependent on the heat applied to the weld.

**Why?**

The heat at the nugget location depends upon process parameters.

**Why?**

The process parameters welding current and cycle time are affecting the nugget diameter.

**Why?**

Optimization of welding current and cycle time is required to achieve proper tensile strength of weld.

So, by analyse phase we come to a point that for solving the problem of rejection level due to low weld tensile strength is optimizing the process parameters such as welding current and weld cycle time.

*(D) Improve Phase Overview*

Improve phase is an important phase of a defined problem to arrive at a feasible solution for improving the sigma level of the process as well as filling up the gap between present and desired quality output.

*Improve Phase for problem*

*Preparation of Test Specimen for Ultrasonic testing and Tensile Testing.*

For preparation of test specimen, the resistance spot welding machine VS-10 model is used.

The test specimen size such as length, width and overlap is mentioned in Table 3.

Table. 3. Test Specimen Size

| Sr.No. | Parameter | Size (mm) |
|---|---|---|
| 1 | Length | 76 |
| 2 | Width | 19 |
| 3 | Overlap | 19 |

Based on this size herein we have taken into consideration the Welding Current and Cycle time value using $L_9$ array as shown in Table 4.

Table. 4. Welding Current and Weld Cycle Time value for Test Specimen

| Sr.No. | Welding Current(kA) | Weld Cycle Time |
|---|---|---|
| Specimen 1 | 7 | 12 |
| Specimen 2 | 7 | 14 |
| Specimen 3 | 7 | 16 |
| Specimen 4 | 8 | 12 |
| Specimen 5 | 8 | 14 |
| Specimen 6 | 8 | 16 |
| Specimen 7 | 9 | 12 |
| Specimen 8 | 9 | 14 |
| Specimen 9 | 9 | 16 |

Now, test specimens are prepared as per table 4 and their image is shown in Fig. 3 as below.

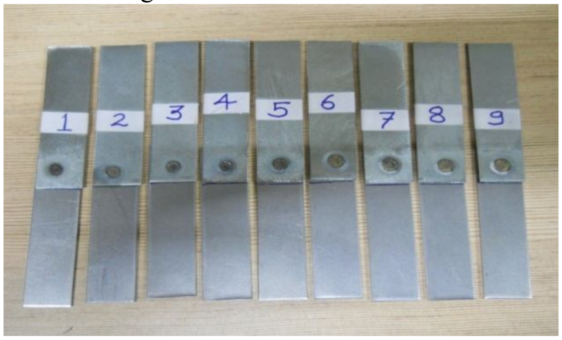


Fig. 3. Test Specimen after spot welding for Ultrasonic and Tensile Testing

*Electrode Grinding Angle and Facts about its effect on Weld Quality*

This is the effective factor on weld quality. The functions of the electrode are mentioned below:

1. It is used to conduct the welding current to the work pieces.
2. It is used for withstanding and transmitting the necessary force to the work pieces to produce satisfactory weld.
3. It is used for dissipating a part of the heat from the work and thus prevents surface fusion.

The electrode grinding angle used for welding of pads to pan in this case is $84^0$ as shown in Fig. 4. It is measured with the help of bevel protractor.

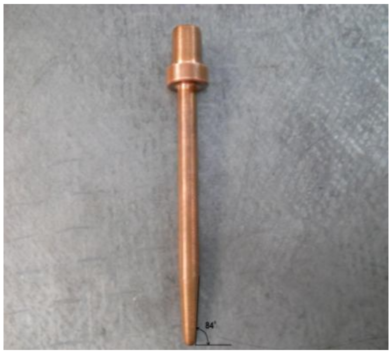

Fig. 4. Electrode angle 840

By referring the different research papers, the facts about electrode grinding angle and its effect on weld nugget in Resistance Spot Welding are mentioned below:

1. If weld size is greater than $4\sqrt{t}$ (where t represents the thickness of the thinnest sheet in combination) then electrode as shown in fig. 4 is used.
2. Electrode angle affects current density distribution in the electrode and work pieces, and

eventually affects the electrode life and nugget formation.

3. The larger the electrode angle, the higher electrode temperature.
4. The electrode with smaller angle has more mass, which could improve the cooling capability of the electrode and help to dump more heat into the electrode and thus greatly alleviate the heat accumulation in the electrode.
5. With the linear increase of the electrode angle, the temperature at the tip surface increased sharply. The temperature at the centre was far higher than that at the edge.

*Ultrasonic Testing of test specimens*

After preparation of the test specimens, they are inspected with non-destructive testing known as ultrasonic testing.

Einstein – II TFT Ultrasonic Flaw detector machine is used for carrying out the test is as shown in Fig.5.


Fig. 5. Einstein – II TFT Ultrasonic Flaw detector machine

Each specimen is assessed by using this machine. The test results are shown in Table 5.

Table. 5. Ultrasonic test results for test specimens

| Sr. No. | Specimen | Nugget Diameter (mm) | Internal Defect |
|---|---|---|---|
| 1 | Specimen 1 | 4.10 | NIL |
| 2 | Specimen 2 | 4.20 | NIL |
| 3 | Specimen 3 | 4.50 | NIL |
| 4 | Specimen 4 | 4.10 | NIL |
| 5 | Specimen 5 | 4.85 | NIL |
| 6 | Specimen 6 | 4.80 | NIL |
| 7 | Specimen 7 | 4.50 | NIL |
| 8 | Specimen 8 | 3.75 | NIL |
| 9 | Specimen 9 | 4.20 | NIL |

*Tensile Testing of test specimens*

After completion of ultrasonic testing, there is another test known as a tensile test is carried out on the test specimens. The Universal Testing Machine used for tensile testing is shown in Fig.6.

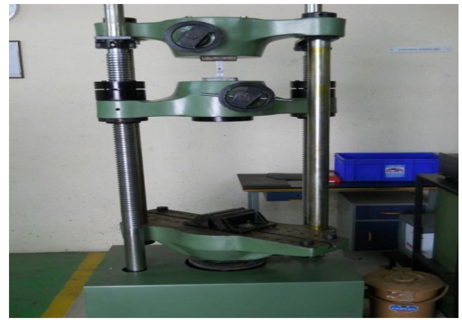

Fig. 6. Universal Testing Machine

After testing the test specimens are failed at a particular tensile strength in $N/mm^2$ and their image is shown in Fig.7.

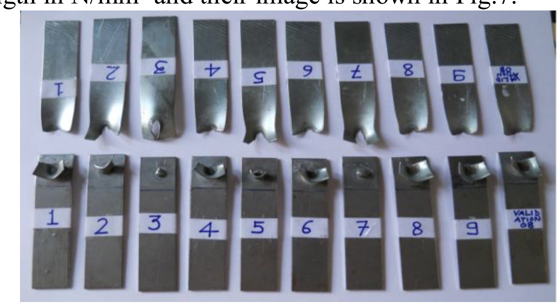

Fig. 7. Specimen failure after Tensile Testing

The results which we obtained of tensile testing of the test specimens are used for finding out the optimum value of the welding current and cycle time to optimize the weld tensile strength and reducing the current rejection level. The result related to tensile testing for specimens are shown in Table 6.

Table. 6. Tensile test results for test specimens

| Sr.No. | Specimen | Tensile Strength ($N/mm^2$) |
|---|---|---|
| 1 | Specimen 1 | 340.86 |
| 2 | Specimen 2 | 326.35 |
| 3 | Specimen 3 | 275.47 |
| 4 | Specimen 4 | 336.36 |
| 5 | Specimen 5 | 254.41 |
| 6 | Specimen 6 | 245.37 |
| 7 | Specimen 7 | 296.78 |
| 8 | Specimen 8 | 443.68 |
| 9 | Specimen 9 | 350.80 |

Taguchi method is used for finding out the optimum value of welding current and weld cycle time for improving weld tensile strength.

*Taguchi method application for problem*

For this phase statistical software is used for creating and analysing the Taguchi design and its analysis.

(1) Then after we can get Main effect plots for S/N ratio – Tensile Strength which is shown in Fig.8 and

Response Table for Signal to Noise Ratios- Tensile Strength which is shown in Table 7.

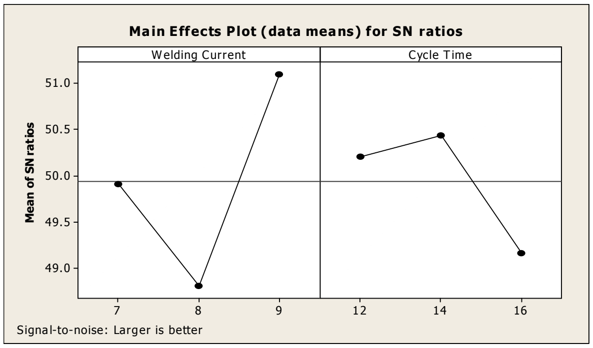


Fig. 8. Main effect plots for S/N ratio – Tensile Strength

Table. 7. Response Table for Signal to Noise Ratios – Tensile Strength

| Level | Welding Current | Cycle Time |
|---|---|---|
| 1 | 49.91 | 50.21 |
| 2 | 48.81 | 50.44 |
| 3 | 51.10 | 49.17 |
| Delta | 2.28 | 1.28 |
| Rank | 1 | 2 |

From this plot of Fig. 8 and response Table 7, we can conclude that welding current with 9kA and cycle time of 14 gives us a high signal to noise ratio. Welding current is highly effective as compared to the Weld Cycle Time.

(2)Then after we can get the Main effect plots for Mean – Tensile Strength which is shown in Fig.9 and Response Table for Means – Tensile Strength is shown in Table 8.

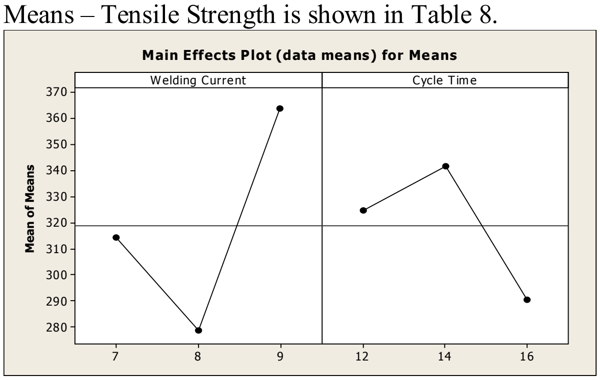


Fig. 9. Main effect plots for Mean – Tensile Strength

Table. 8. Response Table for Means – Tensile Strength

| Level | Welding Current | Cycle Time |
|---|---|---|
| 1 | 314.2 | 324.7 |
| 2 | 278.7 | 341.5 |
| 3 | 363.8 | 290.5 |
| Delta | 85 | 50.9 |
| Rank | 1 | 2 |

From this plot of Fig. 9 and response Table 8, we can conclude that welding current with 9kA and cycle time of 14 gives us a high mean of means. Welding current is highly effective as compared to the Weld Cycle Time.

(3)Interaction plot for S/N ratio – Tensile Strength is shown in Fig.10 and interaction plot for Means – Tensile Strength is shown in Fig.11.


Fig. 10. Interaction plot for S/N ratio – Tensile Strength

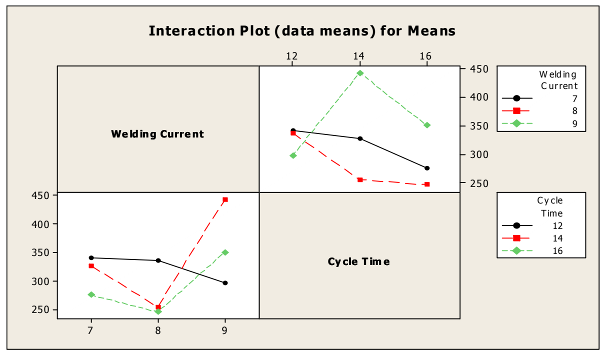


Fig. 11. Interaction plot for Means – Tensile Strength

*ANOVA for problem*

ANOVA is carried out for finding out the highly effective factor as shown in Table 9. It is found that welding current is highly effective.

Table. 9. ANOVA results

| Source | DF | SS | MS | F |
|---|---|---|---|---|
| Welding Current | 2 | 10945.9 | 5472.94 | 1.52 |
| Cycle Time | 2 | 4041.1 | 2020.53 | 0.56 |
| Error | 4 | 14384.4 | 3596.09 | |
| Total | 8 | 29371.3 | | |

The data is applied for the month of April-2015. Then improvement in the result is compared with previous month of March- 2015. There is an improvement in the process output which is shown in Table 10.

Table. 10. Process improvement and result

| Parameters | Before | After | Improvement |
|---|---|---|---|
| Welding Current (kA) | 7 | 9 | Optimized Current |
| Cycle Time | 16 | 14 | Optimized Cycle Time |
| Nugget Diameter(mm) | 4.50 | 3.75 | Optimized Nugget Diameter |
| Tensile Strength($N/mm^2$) | 275.47 | 443.68 | 168.21 |
| Internal Defect | NIL | NIL | Assurance of No Internal Defect |
| Rejection | 4 out of 29 tank (March' 15) | 2 out of 25 tank (April '15) | Reduced Rejection |
| Rejection Cost(Rs.) | 2200 | 1100 | 1100 |
| Rejection Cost (%) | 13.79 | 8.00 | 5.79 |

*(E) Control Phase Overview*

This is the final stage of DMAIC methodology implementation is to hold the gains that have been obtained from the improve stage. In this phase, the new process conditions are documented, and frozen into systems so that the gains are permanent

*Standard Operating Procedure for improvement in problem*

Standard operating procedure for a given problem solution is mentioned in Table 11.

Table. 11. Standard Operating Procedure (SOP)

| Sr.No. | Parameter | Value/Condition |
|---|---|---|
| 1 | Welding Current (kA) | 9 |
| 2 | Weld Cycle Time | 14 |
| 3 | Work piece condition | Clean and free from dirt, rust, etc. |
| 4 | Machine Set up | Properly Maintained |
| 5 | Operator | Skill for welding pads with the pan |

By continuously implementing this parameters and making improvements in the process, it is possible to reduce rejection level of fuel tank G2.

*(F) Results and Discussion*

By implementation of DMAIC methodology and Taguchi method, it is possible to arrive at a solution. The improvements are,

(1) There is an optimization of welding current and weld cycle time for optimization of spot weld tensile strength. The value for welding current 9 kA and weld cycle time 14, there is an optimized spot weld tensile strength of 443.68$N/mm^2$.

(2) The nugget diameter is optimized of 3.45 mm diameter.

(3) There is an assurance of no internal defect.

(4) There is a reduction of rejection of fuel tank G2 from 4 out of 29 (March 2015) to 2 out of 25(April 2015).

(5) There is a reduction of rejection cost of 13.79% to 8.00%. So, there is an improvement of 5.79%.

(6) There is an improvement of sigma level 2.59 (March 2015) to 2.91(April 2015). There is an improvement in sigma level of 0.32.

## IV. Conclusion

By application of DMAIC method and Taguchi method to reduce rejection level of fuel tank G2, it is found that welding current is highly effective.

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