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Reduction of Heat Seal Leak Defect in Lead Acid Battery Assembly Process by Using Structured Problem Solving Approach

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Abstract: ***The objective of this study is to reduce the heat seal leak rejection in the lead-acid battery assembly process using Six Sigma's DMAIC (Define, Measure, Analyze, Improve and Control) methodology. In the DMAIC methodology, Shainin tools and techniques has been used to identify and validate the causes. It was found that material sticking to the hot plate and stringing of the melt is a cause of the problem. The melt that remains on the hot plate degrading and transferring to the subsequent welds, resulting in poor welding. This is suppressed by advanced chromium (Cr^{+}) coating on heat sealing platen. After implementing the solution, the heat seal leak rejections are significantly reduced by 65 % and platen cleaning frequency reduced by50%.***

Keywords: Lead Acid Manufacturing, Lead Acid Technology, Problem Solving in Manufacturing Process

1. Introduction

Assembly is one of the critical processes in lead acid battery manufacturing process. In this process, all the components - plates, separators, cover and terminals are assembled into a battery container and then battery cover permanently seals the container by heat sealing process. A major defect occurs in the assembly process is the leakage at cover and container sealing, generally referred as heat seal leaks. The heat seal leak problem occurs when the seal strength between the battery container and the cover is too low/ no bonding between the cover and container. This leads to acid leakage in subsequent processes and during its service life. Acid leakage from battery degrades the battery performance, leads to corrosion of surroundings and in few cases this creates safety concern. During the battery assembly process each battery cover and container sealing effectiveness verified through the leak testing process, here air pressure drop is considered as the quality requirement which should be less than 0.04 PSI. The batteries which are noted with high air pressure drop than the requirement will be marked as a heat seal leak battery.

In lead acid battery industry from 1960s, battery cover and containers were made with polypropylene and sealing is done through the hot plate welding, this is usually referred as a heat sealing process [1]. The principal heat transfer method for hot-plate welding is conduction. The hot-plate welding process consists of three key steps: the melt phase, the open phase and the sealing phase. The strength of the bond is determined by tensile testing [2].In an endeavor to make sealing process more efficient, various studies have been carried out earlier on hot plate welding process parameters and poly material composition [3-5].

Kaewon et al, studied sealing strength improvement with DOE techniques in VRLA battery, identified that stopper distance of the case, stopper distance of the lid and melting time are significant factors that affect the heat seal strength. Improved sealing strength through the optimal setting of those parameters and achieved a significant reduction in air leakage defective rate[3].

E.Taskiram et al, studied the welding factors and talc ratio influence on welding strength of polypropylene through DOE method. Through this study, arrived optimum welding parameters and talc ratio for the polypropylene material to achieve optimum weld strength and to improve hot plate welding process efficiency [4].

The patent – US005197994A, Method of heat sealing a battery issued Mar. 30, 1993 explained the influence of platen temperature, squeeze between cover and container and depth of melt on the strength of heat sealing bond in battery assembly process [5]. All the studies showed that heat sealing process conditions has significant effect on sealing process efficiency.

The intent of this study is to improve the heat sealing process efficiency of lead acid battery by eliminating the causes of poor cover to container sealing and to reduce the heat seal leak rejections. This study is executed through systematic approach by using Six Sigma DMAIC methodology with shainin/statistical tools.

DMAIC (Define–Measure–Analyze–Improve–Control), the framework of Six Sigma methodology has been well established as bench marking tool for process improvement and helps in problem solving related to manufacturing process. It enables decisions to be made based on actual data and measurement [6].

In Six Sigma-DMAIC methodology, Shainin tools are very effective in manufacturing industries primarily known to produce continuous improvements by eliminating chronic quality problems. Shainin techniques provides the simplest, easiest and most effective ways to arrive the solution [7,8].

In this case study, Shainin tools such as Paired Comparison, Product Process Search, B Vs C analysis were employed to analyze, improve and control the heat seal leak rejections.

2. Case Study

Step 1 – Define

Problem Statement - The major defect observed in the assembly process is heat seal leak. After heat sealing process the bonding between cover and container is verified through air leak test with 5 psi air pressure for minimum duration of 3-5 Sec and pressure drop is measured. The Pareto chart shown in Fig.1explain that heat seal leak contributes about 51% of total assembly rejections; the defect level is 0.15 %. The box plot is shown in Fig. 2 represents the pressure drop in normal and heat seal leak batteries. In heat seal leak batteries, the air pressure drop is 0.09 Psi whereas on normal batteries pressure drop is 0.02 Psi. There is a significant difference in pressure drop. The phenomenon behind this problem is the poor cover and container sealing in heat sealing operation.

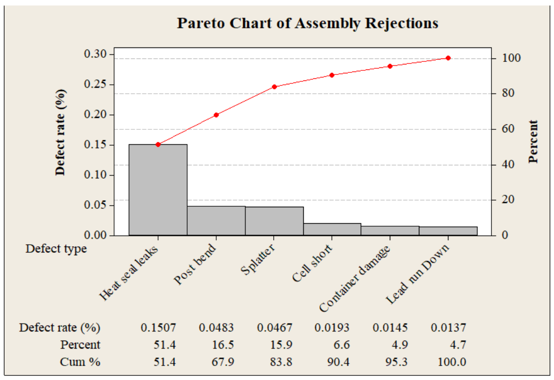


Figure 1: Pareto chart of defect batteries from assembly process

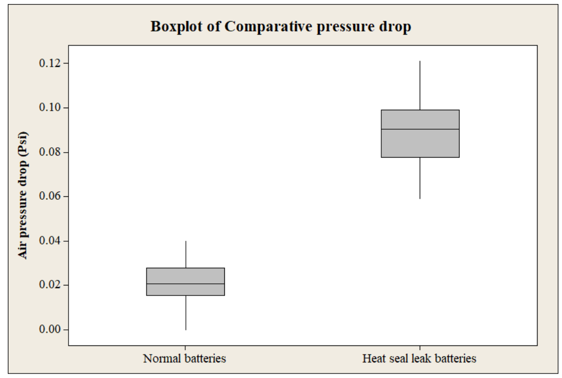


Figure 2: Box plot of normal batteries and heat seal leak batteries air pressure drop

Step – 2 Measure

The purpose of this step is to evaluate the existing process and assessment of current level of process performance. In present study, heat seal leak is one of the major defects from assembly process and is contributing 51% of total assembly rejections. The team identified the factors that could influence the heat sealing process. A cause-and-effect diagram was developed (refer Fig. 3) to identify the potential causes of heat seal leak.

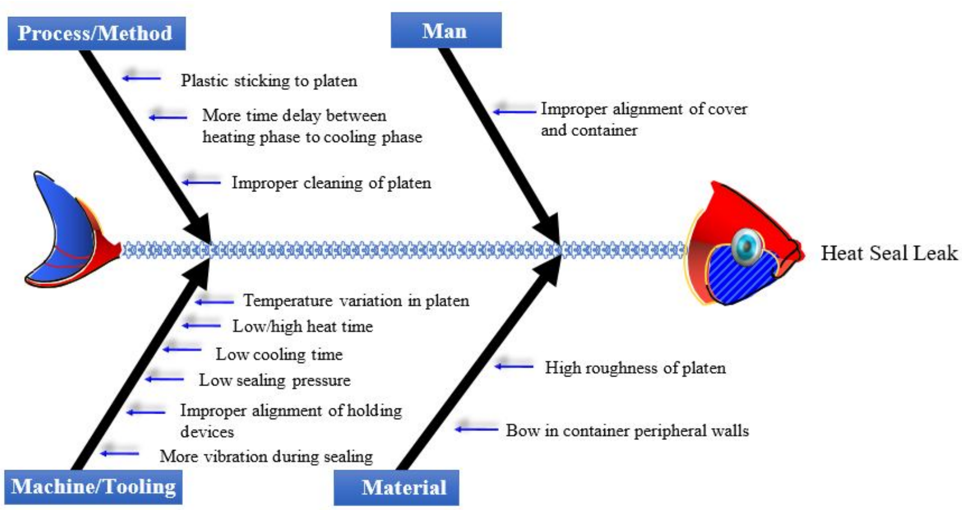


Figure 3: Cause and effect diagram of heat seal leak rejections

After collecting all possible causes through a cause-and-effect diagram, listed down the topmost causes in Table1 by evaluating the existing process data and knowledge.

Step – 3 Analyze

For validating causes three tools were used in this phase i.e., Product Process Search (PPS), Paired Comparison (PC) and Two-Sample T-Test (2-t test) to confirm that either that particular cause is contributing for the problem (or) not.

Table 1: List of causes for heat seal leak

S. No	Cause	Tool used for analysis
i	Heat sealing temperature	Product Process Search (PPS)
ii	Heat sealing pressure	Product Process Search (PPS)
iii	Module height	Paired Comparison (PC)
iv	Poly material sticking to platen	Two-Sample T-Test (2-t test)

Tool 1: PPS (for cause i& ii)
First tool used for analyzing the causes was Product Process Search (PPS), this tool is used for validating process related causes such as heat sealing temperature and sealing pressure.

Data Collection:
Here, the cause and response can be measured on-line (near the machine) without stopping the production. Based on the historical rejection decided 30, 000 no's production as a lot quantity to get adequate number of bad parts. Marked each part with serial number and measured the process parameter for all the parts when the parts is getting produced. Parts response is recorded (good/bad) with respect to serial number. Collected 8 good and 8 bad parts, the data collated in ascending order. Data shown in Table 2 & 3.

Interpretations

- If the minimum and the maximum values belongs to same category, which means cause is not reason for problem.
- In the absence of above condition, draw the transition line from top and bottom where the response changed. Add the no. of data above the top line and below the bottom line to get total count.
- In case, at the transition point same values are repeating then consider ½ count for that. This is applicable only for two repetitions.
- If total count $\geq$ 6, which means there is a correlation with the cause, then cause is contributing for the problem. If < 6, which means there is no correlation with the cause, then cause not the contributing for the problem.

Results
i) Evaluation of heat sealing temperature

Table 2: PPS analysis of heat sealing temperature

S.No	Sealing Temperature (°C)	Response	
1	340	Bad	
2	340	Bad	
3	342	Bad	Transition line
4	342	Good	
5	345	Good	
6	345	Bad	
7	347	Bad	
8	350	Good	
9	350	Bad	
10	352	Good	
11	352	Bad	
12	355	Good	
13	355	Good	
14	358	Bad	Transition line
15	358	Good	
16	360	Good	

Analysis:
The total count is 4.

Which means, the products made with low sealing temperature and high sealing temperature are not causing significant difference in the product quality.

It is concluded that heat sealing temperature is not contributing to this problem

ii) Evaluation of heat sealing pressure

Table 3: PPS analysis of heat sealing pressure

S.No	Sealing Pressure (Kg/Cm2)	Response
1	4.50	Good
2	4.50	Good
3	4.50	Bad
4	5.00	Bad
5	5.00	Good
6	5.00	Bad
7	5.50	Bad
8	5.50	Good
9	5.50	Good
10	6.00	Bad
11	6.00	Bad
12	6.00	Good
13	6.50	Good
14	6.50	Bad
15	6.50	Bad
16	6.50	Good

Analysis:
Both the minimum and maximum value belongs to same category i.e. good.
Which means maximum and minimum heat sealing pressure is able to produce same quality of products

It was concluded that heat sealing pressure is not contributing to the problem

Tool 2: PC (for cause iii)
Second tool used for analyzing the cause was Paired Comparison (PC), identified cause can be measured on the good and bad parts i.e., module height of the battery.

Data Collection:
Here the cause can be measured off-line on the good and bad parts. From the production lot, collected 8 good and 8 bad parts and measured the module heights. That data arranged in ascending order along with response. Data shown in Table 4.

Interpretations
Data interpretation guidelines are similar to Product Process Search (PPS).

Result

iii) Evaluation of module height

Table 4: PC analysis of module height

S.No	Module Height (mm)	Response
1	226.16	Bad
2	226.22	Bad
3	226.36	Good
4	226.40	Good
5	226.42	Bad
6	226.49	Bad
7	226.52	Good
8	226.54	Bad
9	226.58	Good
10	226.60	Good
11	226.65	Bad
12	226.68	Good
13	226.77	Bad
14	226.80	Good
15	226.98	Bad
16	227.10	Good

Transition line (between rows 2 and 3)

Transition line (between rows 15 and 16)

Tool 3: (for cause iv)

Third tool used for analyzing the cause was Two-Sample T-Test (2-t test), the identified cause should be validated between different conditions i.e., platen cleaning frequency. 2-t test applied to compare whether the average difference in heat seal leak rejection % between two conditions (existing vs trial) is really significant.

Data Collection

In this case, carried the trial with regular platen cleaning frequency and increased platen cleaning frequency for one week with each option, existing cleaning frequency (4times/shift), and increased frequency (8 times/shift). Recorded the heat seal leak rejections in both the conditions and analyzed the data through 2-t test in Minitab-16, the results represented through Box plot as shown in Fig 4.

Interpretations

As per the Two Sample T Test analysis, If P value is <0.05, which means that there is a difference between the two groups with 95% confidence limit.

Results:

iv) Evaluation of material sticking to the platen

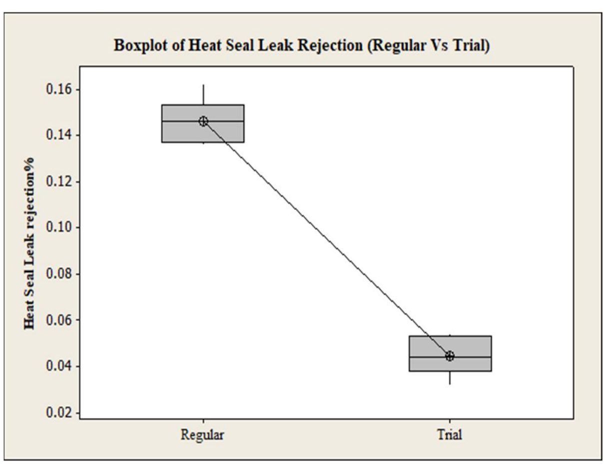


Figure 4: Two-Sample T-Test and CI: Regular, Trial

Analysis:

The total count is 3.

Which means, the products with low module height and high module height not causing significant difference on the product quality.

It is conclude that module height is not contributing to the problem.

<u>Two-sample T for Regular vs Trial</u>

	N	Mean	StDev	SE Mean
Regular	7	0.14586	0.00965	0.0036
Trial	7	0.04457	0.00804	0.0030

Difference = mu (Regular) - mu (Trial); Estimate for difference: 0.10129

95% CI for difference: (0.09084, 0.11173)

T-Test of difference = 0 (vs not =): T-Value = 21.34;

<u>P-Value = 0.000</u>

Analysis:

In this case, the P value is 0.000.Which shows that there is a difference with regular and trial average rejection% with 95% confidence limit. Box plot in Fig 4, represents that the average heat seal leak rejection is reduced from 0.146% to 0.045%.

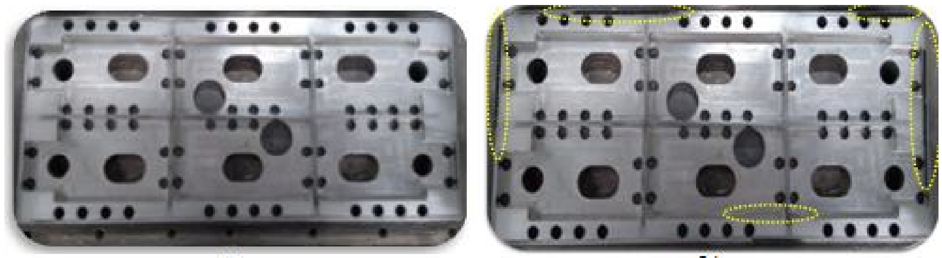
It is concluded that material sticking to the platen was contributed to the problem

In Table 5 summarized the validation results of potential causes

Table 5: Analysis summary of causes

S. No	Cause	Tool used for analysis	Result
i	Heat sealing temperature	Product Process Search (PPS)	Not a cause
ii	Heat sealing pressure	Product Process Search (PPS)	Not a cause
iii	Module height	Paired comparison (PC)	Not a cause
iv	Poly material sticking to platen	Two-Sample T-Test (2-t test)	Significant cause

From analysis, it is confirmed that poly material sticking to the platen is the reason for poor sealing of cover and container. Fig.5 representing the good and bad platen images.



(a) (b)

Figure 5: (a) Good platen surface (cleaned); (b) Bad platen surface (plastic material sticking)

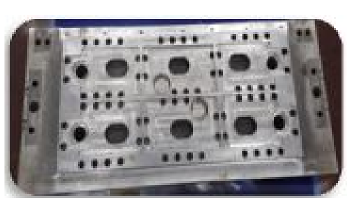
Step – 4 Improve

The conclusion of earlier phase is used as an input to this phase. This phase is to implement the solution and verify its workability in eliminating the significant cause of the problem i.e., material sticking to the platen. To improve, two different types of coating materials on heat sealing platen are examined for the hot plate welding process. One is the aerosol which should be sprayed on the platen and another is advanced Cr^+ coating. Material characteristics are shown in Table 6. These inert materials are applied (or) coated on the platen surfaces as a thin film. The coating is expected to create low friction on platen surface which helps easy releasing of poly material during the sealing process and act as good releasing agents. Due to this material sticking to the platen will be minimized.

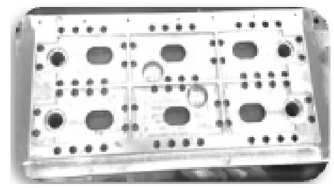
Table 6: Material characteristics of coating materials

S.No	Description	UOM	Aerosol Spray	Cr^+
1	Colour	-	White	Rainbow
2	Material	-	Dry fluorocarbon resin	Chrome base
3	Density	gm/ml & gm/cc	1.1	5.9
4	Maximum service temperature	Deg. C	650	700
5	Coating thickness	µ	15	8
6	Coefficient of friction (dry against steel)	-	-	0.3–0.5

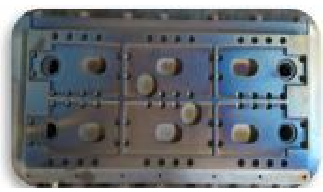
The heat sealing platen (two different) was coated with aerosol spray and advanced Cr^+. Heat sealing process using the coated platen was carried out for three days. Fig.6 represents the platen appearance (top area) with and without coating. Heat seal leak rejection % between the existing platen and modified platens were compared. The results are shown in Table 7 and observed improved results with Cr^+ coated platen.



(a) Platen appearance: Light grey colour and slightly rough surface



(b) Platen appearance: Silver color and smooth surface



(c) Platen appearance: Rainbow colour and Smooth surface

Figure 6: (a) Regular platen; (b) Aerosol coated platen; (c) Cr^+ coated platen

Table 7: Heat seal leak rejection % with different heat sealing platens

S.No	Experimentation	Heat seal leak rejection%
1	Regular platen	0.15
2	Aerosol coated platen	0.11
3	Cr^+coated platen	0.05

After verifying the solution, it was observed that Cr^+ coated platen improves the heat sealing process. The amount of improvement is validated with B Vs C tool (B-Better condition, C-Current condition), which is a confirmation tool to verify whether the action taken has actually improved the process or not. In this case, 3B and 3C (without overlap) were selected to validate the impact of improvement action viz. Cr^+ coating heat sealing platen rejection.

Data Collection

Carried the heat sealing process with better condition (Cr^+ coated platen) and current condition (regular platen) alternatively with batch quantity of 10,000 No's for 3 batches and captured the response(heat seal leak rejection%)

Interpretation

a) Check whether there is overlap or No overlap in the 3 batches of data
b) If there is no overlap, the identified cause-solution is correct/ In case if there is overlap, the identified cause-solution is 'not correct'
c) Once it is validated as 'correct', quantify the amount of improvement through the below steps
   - Find out the average of 'B' and 'C' conditions
   - Find out the difference between the averages (X_b – Xc)

- Find out the Sigma of 'B' values (Sigma (b))
- K value (for sample size 3, 3 and 95% confidence level) – 4.2
- If $(X_b - Xc) >= K * \text{Sigma (b)}$, then the conclusion is $(X_b - Xc)$ improvement has taken place at 95% CL

Analysis & Results:

As shown in Table 8. Since the response data exhibited no overlaps between B condition (with modification) and C condition (without modification), the team concluded that the significant cause and solution is correctly identified and quantified the amount of improvement as shown in Table 9. It is also concluded that the improvement has taken place at 95 % confidence level.

Table 8: Heat seal leak rejection% in Better and Current conditions

Batches	With modification Better Condition (B) %	Without modification Current Condition (C)%
1	0.05	0.15
2	0.04	0.13
3	0.04	0.14

Table 9: Quantifying the improvement

Better condition (B)	With modified platen
Current condition (C)	With existing platen
Sample size	3B & 3C
Sample type	Batch
Response decided for monitoring	Heat seal leak rejections (%)
Historic rejection	0.15%
Batch quantity	10,000 No's
Is alternating between B and C conditions possible	Yes
Historic rejection level (%)	0.15
Average of B condition (%)	0.04
Average of C condition (%)	0.14
Amount of Improvement	70%
Sigma of B condition data	0.005
Difference between averages (Xb – Xc)	0.10
K value	4.2
K* Sigma of B condition data	0.021

Interpretation: As Xb – Xc > (k* Sigma B) there is a statistical improvement @ 95 % Confidence level

Step -5 Control

The focus of the control phase is to sustain the gains of the improvement phase. This is usually achieved by documentation and standardization of the control measures. In this case, the heat seal leak rejections for three months is monitored, the heat seal leak rejections were reduced from 0.15 to 0.05% as shown in Fig 7.

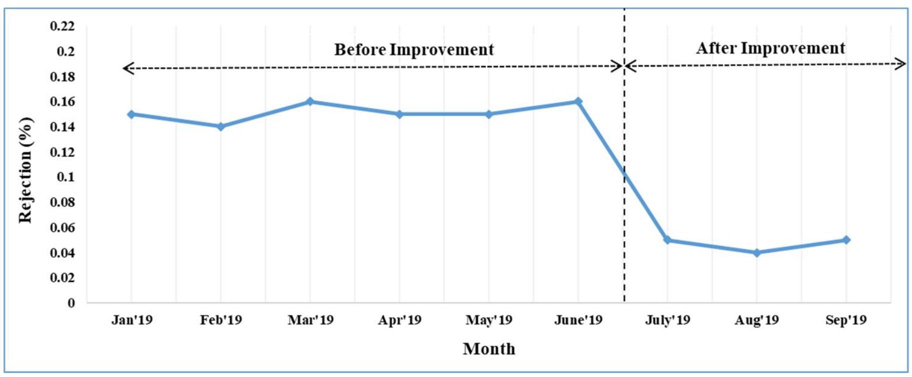


Figure 7: Heat seal leak rejection % before and after improvement

3. Conclusion

This case study was carried out systematically to improve heat-sealing process efficiency. Problem solving techniques were used to identify various potential causes and funneling out the significant cause. Material sticking to the hot plate and stringing of the melt causing poor cover and container sealing were identified. Sticking was reduced by the coating of heat sealing platen with advanced chromium (Cr^+). Through this solution heat seal leak rejection reduced from 0.15 to 0.05%, platen cleaning frequency reduced to half and machine ambience improved due to the reduction of material falling. The improvement is used for horizontal deployment in other variants in the process.

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