Enhancement of Efficiency and Reduction of Grid Thickness Variation on Casting Process with Lean Six Sigma Method

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Abstract. In a lead acid battery industry, grid casting is a process that has high defect and thickness variation level. DMAIC (Define-Measure-Analyse-Improve-Control) method and its tools will be used to improve the casting process. In the Define stage, it is used project charter and SIPOC (Supplier Input Process Output Customer) method to map the existent problem. In the Measure stage, it is conducted a data retrieval related to the types of defect and the amount of it, also the grid thickness variation that happened. And then the retrieved data is processed and analyzed by using 5 Why’s and FMEA method. In the Analyze stage, it is conducted a grid observation that experience fragile and crack type of defect by using microscope showing the amount of oxide Pb inclusion in the grid. Analysis that is used in grid casting process shows the difference of temperature that is too high between the metal fluid and mold temperature, also the corking process that doesn’t have standard. The Improve stage is conducted a fixing process which generates the reduction of grid variation thickness level and defect/unit level from 9,184% to 0,492%. In Control stage, it is conducted a new working standard determination and already fixed control process.

Keywords: battery, grid casting, lean six-sigma, DMAIC.

1. Introduction

Casting stage in the process of battery manufacture is a stage that determines the quality of grid plates which will be processed in the next steps. Grid that has been made is transferred to pasting area to attach paste on the plate. However, there are so many defects on the grid production processes. Types of defect that happens on grid are hole, fragile, oblique, miss-trim and crack. Fragile, crack and hole are types of defect that have the highest percentage among other defects that dominantly lowered production level. The grid produced also has a high thickness variation which is not in accordance with the determined specification and creates rejects or disturb the further production processes in the battery making processes. Grid defect problems makes the company could not reach production target for fulfilling the existing demand.

2. Research Methods

This experiment was conducted by using lean six sigma method in the form of DMAIC (Define-Measure-Analyse-Improve-Control)[2]. In every stage on DMAIC method, appropriates supporting tools were used.

2.1. Define

Figure 1 show the casting process efficiency. The efficiency level in casting process is measured by calculating the amount of grid production a month divided by ideal amount of grid production at
the whole total production time available in that month. The higher defect/reject rate and idle in production would lower the amount of grid production. Because grid was a main component consumed in the following processes, low grid production would affect to the production level of the batteries.

2.2. Measure

Figure 2 shows the Pareto chart of casting process for June 1st – June 6th 2016 period. It is shown that the highest donator on waste is caused by defect/reject. Rejected grid needs to be reprocessed, so this matter causes wasting. Figure 3 is the amount of defect of production result for each type of defect that was obtained through records by company when casting production process was running for June 13th – September 1st 2016 period. It was shown that only 3 main defect dominates, which are the problem of fragile, holed and cracked grid.

Table 1 is a retrieved data from company related to the amount of defect that happens for every type of defect in casting process for August 25th, 26th and 31st 2016 period. Grid production level for those 3 days was 30150 grid, with total defect that happened was 2769 grid. From this data, it could be
known that the defect/unit level that happened before the improvement process is conducted is 9,184%.

**TABLE 1. Defect Level Before Improvement**

|          | Aug 25th | Aug 26th | Aug 31st |
|----------|----------|----------|----------|
| Fragile wire | 104      | 1056     |          |
| Crack     | 851      |          |          |
| Hole      |          |          | 758      |

Figure 4 shows grid thickness graph for CAL 1.5 type which was measured on November 2016 by taking 30 grids randomly sampled which was measured on four upper sides and four lower sides of the grid. Grid CAL 1.5 type has a thickness specification standard of 1.5 mm with permitted tolerance by the company for production of every grid type is 5% from standard thickness. So, grid CAL 1.5 type has lower tolerance limit of 1.425 mm and upper tolerance limit of 1.575 mm. But, it is shown on the graph that this thickness standard was not achieved and it’s even far below the expected specification standard.

![Interval Plot of Grid Thickness Data](image)

**FIGURE 4.** Graph of Grid Thickness Data on Every Side for Grid Cal 1.5 Type

2.3. Analyse

The analyze stage is where root cause of the problem inspected. Figure 5 shown defect called flash that retrieved at December 3rd 2016 during casting production. Flash is not a fatal defect. Small flash can still pass the inspection stage and can be used for the next step, but when there are too many flash on the grid, this grid will get into the reject category because it will potentially disturb the pasting process. It makes paste material not attached properly causing hole defect on the grid in pasting process. Grid with many flashes on the main frame or ear/lugs grid is also included into the reject product because too many flashes on the main frame or ear/lugs grid could disturb further processes.

![Grid of Casting Production Result](image)

**FIGURE 5.** Grid of Casting Production Result on December 3rd 2016 Which Had Flash Type of Defect and Also a Fragile Grid
In figure 6, it is shown that the wire grid is not connected, it is called run out. Hole/unfilled type of defect is also included into reject product because it’s potentially causing the grid to have different voltage from standard specification because electricity can’t flow. It can affect the battery performance. Run out also happens in ear/lugs area that will disturb the welding process. Unfilled/run out type of defect can happen caused by the temperature is overly low on the mold, causing molten metal on the riser on the upper part can’t fulfill the mold chamber which starts to freeze and the volume shrinks beforehand.

Figure 7 shown the other defect that the wire and the main frame are not merged to each other. It is caused by fragile grid so it was easily break on the wire part or main frame. Grid that had fragile type of defect was taken to be used as a further observation sample and all of the observed samples were taken from the same grid. The observed samples were on the wire part that was broken, on the upper frame and lower frame that weren’t broken by using microscope. The observed broken sample wire was not rubbed beforehand to see the broken pattern. The upper and lower parts of the main frame sample were rubbed beforehand because it was aimed to see the inner condition of the grid.

In figure 8, it is shown that the broken pattern on the wire grid a brittle fracture. This brittle fracture could happen due to several things, such as inclusion/impurities in that part so it has different properties with the original properties from the strong and resilient lead-antimony alloy properties [1].

FIGURE 6. Grid As A Result Of Casting Production On December 3rd 2016 Which Has Hole/Unfilled Type Of Defect And Also Fragile Grid

FIGURE 7. Grid Production Result on December 3rd 2016 which had a crack and fragile type of defect

FIGURE 8. Microscope Observation Result on The Wire Part Which Is Broken (Top) And on The Wire Connection Which Is Broken (Bottom), With 100x Magnification
Figure 9 is an observation sample from the upper part of the main frame grid, it is shown that this part has dark/black area. The dark/black area that is evenly spread shows that the inside of the grid has many inclusions. Inclusions on the grid as a result of casting process could be the inclusion that arises due to molten metal which has many inclusions since the beginning of the process, then it comes in to the mold when the grid molding is being conducted. From the observation, this dark/black area has a huge possibility as an oxide from lead-antimony, because of the addition of antimony on lead could increase the oxide level on the molten lead to the air\[4\].

Table 2 is 5 Why’s table that is used to help finding root of the problem that happens in casting process by finding the problem first and then finding the causes gradually until getting root of the problem which is the main cause. This matter could be used to find root of the problem and potential failure that could happen as well. Root of the problem and potential failure will be used to determine the formulation of action plan of casting process improvement.

| Grid thickness varies | Why 1          | Why 2                                         | Why 3                                         | Why 4                                      |
|----------------------|----------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------------|
|                      | Wrong corking process | No standard/working instruction for corksing process | High oxidation level on area that is exposed to air | No cover on melting pot and ladle |
| Grid has crack/defect| Inclusion on the grid | High dross level on casting process that is exposed to air | High oxidation level on area that is exposed to air | No cover on melting pot and ladle |
| Grid has crack/defect| High shrinkage level | Overly high temperature gradient | Overly high ladle temperature and overly low mold temperature | |
| Grid has hole type of defect | Overly fast solidification | Overly high temperature gradient | Overly high ladle temperature and overly low mold temperature | |
| Grid has hole type of defect | Surface layer of the mold is too thick | Error on corksing process | No standard/working instruction for corksing process | |

2.4. Improve
2.4.1. Changing on Temperature Standard for Casting Process

Overly high temperature standard usage on melting pot area (460°C), feedline pipe (482°C) and ladle (570°C) needs to be changed considering an overly high temperature usage only aims to make sure that the lead-antimony is in liquid condition, whereas the lead-antimony has already reached the melting point at ± 327°C \[3\]. The temperature that is used on melting pot, feedline pipe and especially ladle needs to be changed to lower temperature to avoid overly high temperature gradient with mold temperature. Moreover, temperature of the upper mold is supposed to be higher than the lower mold, so the solidification process could be started from the lower mold.

| TABLE 3. Recommendation for Temperature Standard Changing on Casting Process |
Table 3 shows old temperature standard, experiment temperature and new temperature standard recommendation for each casting process. Experiment temperature is temperature that is used as an experiment when the production process is on the run, the given value is based on analysis and literature study that has been done before. The given new temperature recommendation is based on analysis and literature study that was conducted. The difference of experiment temperature usage between one process to the other is not too high, it is meant to improve the temperature gradient not too high so the shrinkage level which is occurred when the grid is in solidification process won’t be too high because the shrinkage level will get lower as well as the temperature gradient that is used. The decrease of temperature gradient is obtained by decreasing the temperature of ladle, increasing the temperature on the upper mold and decreasing the temperature on the lower mold. This temperature gradient is possible to make the solidification process occurs sequentially, that is from the lower part to the upper part. New temperature recommendation on melting pot, feedline pipe and ladle is 460°C, this is meant so the temperature gradient between ladle and mold is not too low and not too high. An overly low temperature gradient between ladle and mold could cause an overly fast solidification level on the mold, so it could complicate the movement of molten metal to fulfill the room on casting process. An overly high temperature gradient on ladle and mold could cause waste of energy and overly high shrinkage level that occurs on casting process. Melting pot uses burner with gas fuel and feedline pipe as well as ladle use electric heater, so the higher the temperature gradient that is used, the more waste of energy as well.

2.4.2. Dross Cleaning on Casting Process

Figure 10 is ladle sighting before and after cleaned from dross. Previously, dross that was shaped from the previous casting process, especially on ladle, was not cleaned beforehand before the
casting process was started, dross was left to flow and reduced along with the running of casting process. But, from this experiment, it is known that there should be no dross in grid casting process because dross was known to be the cause of inclusion on grid of casting process result, so this matter causes the changing of all properties of grid lead-antimony and also potentially causes the defect problem on grid. By knowing these conditions, dross cleaning on ladle should be done before casting process is started to minimize dross that gets in the grid casting process.

Figure 11 shows ladle that hasn’t been covered and ladle that has already covered. Cover giving aims to not to expose the molten metal directly to open air continuously. Cover should be given especially on the ladle part considering ladle is a process right before the molten metal gets in to the mold. It’s intended for molten metal in the ladle not to react to open air continuously, because this is potentially causing dross formed, so it is expected that ladle always has low dross level, even there is no dross at all.

2.4.3. Corking Process Improvement

Recommendation on the corking process are (i) Clean properly both part of the mould (movable mold and stationary mould) with brass brush, (ii) Spray the corking solution on each part of the mould with distance for about 50 cm in front of the mold at moderate and constant speed, following the flow just like on the given illustration on Figure 12 perpendicularly with mold (not at an angle), (iii) Pour talk powder evenly on both surface of the mold.

![Figure 12. Illustration of Recommended Corking Process Movement](image)

2.4.4. After Improvement Data

|          | Dec 6th | Dec 10th | Dec 11th | Dec 17th | Dec 18th |
|----------|---------|----------|----------|----------|----------|
| Hole     | 23      | 19       | 21       | 24       | 15       |
| Fragile  | 18      | 17       | 17       | 17       | 12       |
| Crack    | 13      | 16       | 12       | 13       | 16       |

Table 4 is data of the amount of casting process production result defect which was obtained after action plan has been conducted. It is shown that there is a significant reduction of defect after action plan was conducted. After observation on casting process, it is known that the highest defect level happens when casting process is just started and after stable, the process will generate grid that is relatively has small defect. The reduction of defect level is a result from action plan implementation which is ladle cleaning from dross before casting process is started, temperature changing on casting process according to the new temperature recommendation, changing of corking process and cover addition on ladle. Grid production level for those 5 days is 51000 grids, with the occurrence of total defect is 251 grids. From this data, it is known that defect/units level after improvement process has decreased to 0.492%.

Figure 13 shows graph of grid thickness data on each side which was measured by using the same method after action plan was conducted. From the data above, it is shown that grid thickness variation decreases and grid that was generated has thickness close to the standard and gets in to the specification limit given by company, which is 5% from thickness standard. The reducing of grid thickness variation was obtained by doing the new recommended corking process. The new corking process is possible for the operator to do a uniform layering process on all side of the mold, so it is obtained a relatively uniform grid from casting process production result.
Conclusion

The conclusions that was obtained from the experiment about Enhancement of Efficiency and Reduction of Grid Thickness Variation on Casting Process with Lean Six Sigma Method are:

1. Fragile and crack type of defects are caused by the amount of inclusion in casting process so the overall material doesn’t have uniform properties, and also caused by an overly high ladle temperature usage and overly low mold temperature so the shrinkage level that happens on solidification process becomes high. Grid that doesn’t have uniform structure overall then it can’t maintain its structure very well on shrinkage process.
2. Inclusion on the grid is an oxide from lead-antimony which is on the ladle then it gets into the casting process, this causes the molding result doesn’t have a uniform property overall.
3. Hole/unfilled type of defect is caused by an overly high temperature gradient between ladle and mold. The temperature of upper mold is too low, causing the solidification process of molten metal will happen too fast, so the molten metal will have obstacles to fulfill the empty space on the mold.
4. There is no standard for corking process, which causes the conducted corking process, is not uniform between one operator to the other. It leads to different thickness on mold layering that could cause grid thickness variation and overly thick corking layer could cause hole type of defect on grid/production result.
5. Overly thin corking layer on the flat side of the mold could cause flash type of defect because it can make that part not covered perfectly when casting process is conducted. Overly thick or overly thin on cavity part of the mold could cause grid thickness variation on casting process result.
6. The given improvement suggestion consists of giving new temperature recommendation, cleaning ladle from dross, giving cover on ladle to avoid dross and recommendation of corking process standard.
7. After action plan has been done, thickness variation on grid of casting process result decreased and the defect level on casting process is decreasing from 9,184% to 0,492%.

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