Defining-Measuring-Analysing-Improving-Controlling (DMAIC): Process and Improve Stability in Carbon Steel Industry

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Abstract. Phosphating is most common method for surface treatment and finishing of ferrous and nonferrous metal. It has excellent corrosion resistance, wear resistance, adhesion and lubricating properties besides its economic values and speed of application. Steel is one of the cheapest materials used in various industries and it requires corrosion resistance therapy. This study aims to provide possible solution to the rusty issue on carbon steel product by improving coating stability using Defining-Measuring-Analysing-Improving-Controlling (DMAIC) method. The result proposed that zinc phosphate coating material has to replace current iron phosphate coating due to the former is more corrosion time resistant than that of the latter.

1. Introduction
The most commonly used metal pre-treatment method for the surface treatment and finishing of ferrous and nonferrous metals is phosphating. It plays a major role in the automotive, process and appliance industries because of its economy, speed of application and ability to provide excellent corrosion resistance, wear resistance, adhesion and lubricating properties [1]. The purpose of zinc phosphate coating is enhancing the aesthetical of product. Steel is one of the cheapest materials used in construction and one that requires corrosion resistance therapy. A hot-dipped galvanization is a common choice among traditional coatings, such as paint coats or galvanization, as it is maintenance-free, highly corrosion-resistant and low-cost [2]. Others, the crystal structure of zinc phosphate coating provides high wear and friction resistance. This property makes it an excellent choice for steel frame products joints. With the advantage of zinc phosphate, this was gained more attention in many sheet metal fabrication companies.

We are facing many customer complaints related to rusty issue of their product. The data collection from June 2019 until April 2020 revealed that there were 20 cases reported related to rusty issue. This is very serious issue that will affect to company business and relationship to customers. The effect also will definitely be on hold from rewarding New Product Introduction (NPI) due to company continuously not fulfilling customer’s expectation on quality matrix. In every business, good quality is one of the most crucial factors that an organization needs to achieve in order to provide an essential service for customer satisfaction which eventually leads to customer loyalty. Thus, continuous improvement needs to be done to overcome the problems. The aim of this research is to find out possible solution to overcome rusty issue for carbon steel product and improve on coating stability of product by using DMAIC method.
2. Literature Findings

Surface treatment is considered to be an effective method of preventing the formation of rusty. Commonly, used surface treatments include organic materials (oils, paints), metals (zinc, aluminium, nickel) and inorganic coatings. Metal coatings also provide good benefits against early rusting but decrease the grade of the steel in practical applications. Phosphating is a chemical conversion treatment which covers the steel surface with a continuous and complete electrical isolation layer of insoluble crystalline phosphates which also adhere to the matrix metal [2]. This zinc phosphate coating material was used as improvement stage to overcome rusty issue for carbon steel materials.

Among the several different quality control techniques that can be regarded as quality assurance strategies, two key ones are used in the six-sigma concept, this approach is focused on process enhancement according to the Deming process. It is an enhancement of the operation in several different areas of the business [3].

First stage is defining, the main aim of this stage is to check whether the steps that should be taken to address the issues are related to the organization's goals and whether there is support from the management and availability of the resources needed. Second step is measuring which concerns is gathering information about processes which are going to be improved. Its focus on information which is needed in order to better understand all the processes in organization, customers’ expectations, suppliers’ specifications and identification of the possible places where a problem may occur. In analyse stage different tools and methods are used to find root causes, assess the risk and analyse data. To confirm the analysis some samples should be performed and potential problems have to be proven to be real problems. Improvement stage is goal of this stage is to take necessary information to create and develop an action plan in order to improve the functioning of the organization, financial aspects and customer relationship issues. Lastly, control stage is about confirmation if changes implemented at the improve stage are sufficient and continuous by verifying the quality of the improved process [4]. Six sigma allows implementing scientific methods in the organization to deliver the best value to the customers.

3. Methodology

To achieve as per goal setting, team was decided to perform lean six sigma methodology, DMAIC were chosen because this structure approach is useful in any situation where we need to improve a complex process [5,6]. Besides, it helps to improve team and organization communications [7]. This leads to improved performance overall, and ultimately this can filter through to happier customers [5]. Below Figure 1, show a DMAIC process sequence and definition of each process.

| No. | Phase  | Definition                                                                 |
|-----|--------|-----------------------------------------------------------------------------|
| 1   | Define | Define the problem, improvement activity, opportunity for improvement, the project goals, and customer (internal and external) requirements. |
| 2   | Measure| Measure process performance.                                                |
| 3   | Analyse| Analyse the process to determine root causes of variation and poor performance (defects). |
| 4   | Improvement | Improve process performance by addressing and eliminating the root causes. |
| 5   | Control | Control the improved process and future process performance.                |

**Figure 1.** DMAIC process sequence and definition

DMAIC methodology begins with forming a team member and drafting the timeline of the project, refers to Figure 2. This is to ensure that there are no gaps between each phase of the project. This timeline also functions as to illustrate the project schedule and ensure meeting the goal.
4. Data Analysis and Findings

4.1 Define
In define phase, found out iron phosphate coating have disadvantages for example flash rusting in Figure 3 happen too fast; most of customer feedback after received a product found out there a small rusting area which also can impact on product reliability.

![Flash rusting happen at carbon steel materials](image)

Figure 3. Flash rusting happen at carbon steel materials

4.2 Measure
In the measure phase, all the data related to customer feedback and internal issue have been plotted using Pareto chart to analyse the frequency issue happen. Below Figure 4 show the data collected from Jun 2019 until April 2020. Based on plotted Pareto chart, found out rusty issue is the top issue highlighted 20 cases, with cumulative frequency 40%.

![Pareto diagram customer and internal feedback from June 2019 until April 2020](image)

Figure 4. Pareto diagram customer and internal feedback from June 2019 until April 2020
4.3 Analyse
In this phase, major rusty defect was identified and happens at treatment stage. Therefore, to analyse further on root cause and failure mode, Failure Mode and Effects (FMEA) was used to identify potential failure mode, potential effect of failure, potential root cause and potential of failure mechanism, refer below Figure 5 FMEA for treatment process. To find more details on analysis, why-why analysis was done to uncover the root causes, refer Figure 6.

| Process Function | Potential Failure Mode | Potential Effect(s) of Failure | Severity | Potential Cause(s) of Failure | Occurrence | Current Process Controls Prevention | Current Process Controls Detection | Detection | RPN |
|------------------|------------------------|-------------------------------|----------|------------------------------|------------|------------------------------------|-----------------------------------|----------|-----|
| Treatment        | 1)Wrong treatment      | 1)Cost increased              | 3        | 1)Indicated wrongly for PS   | 3          | 1)Visual inspection               | 2)QC inspection                   | 3        | 27  |
|                  |                        | 2)Effect the current capacity |          | 2)Inadequate training        |            |                                    |                                    |          |     |
|                  |                        | 3)OTD effect                  |          |                              |            |                                    |                                    |          |     |
| Rust             | 1)Cost increased       | 1)Wrong treatment sequence    | 6        | 1)Wrong treatment sequence   | 3          | 1)Visual inspection               | 2)QC inspection                   | 3        | 54  |
|                  | 2)Effect the current capacity |                      |          | 2)Inadequate soaking time    |            |                                    |                                    |          |     |
|                  |                        | 3)Inadequate training         |          |                              |            |                                    |                                    |          |     |

Figure 5. FMEA for treatment process

| No. | Question Answer | Answer |
|-----|-----------------|--------|
| Why 1? | Why product found rusty? | Product going thru too many process before ship out |
| Why 2? | Why product going thru too many | Products design complexity |
|     | process before ship out? |        |
| Why 3? | Why products design complexity? | Coating material is not suitable to sustain processing time |

Figure 6. Why-why analysis on rusty issue

4.4 Improve
After found out the main root cause in analyse phase, improvement need to be done to overcome this issue. Brainstorming session was done and select zinc phosphate coating is a proposal to replace iron phosphate coating. This proposal was done due to their advantage such as corrosion resistance is longer compared to Iron Phosphate which is 750 to 1000 hours.

Design of Experiment (DOE) Figure 7 was used to solve problems from complex processes where there are many factors influencing the outcome and where it is impossible to isolate one factor or variable from the others. DOE result found 45mins of immersion time for zinc phosphate 640mg/ft² is an optimum value to ensure coating materials completely adhere to substrate. The more coating weight value, this can give more lasting corrosive resistant.

Figure 7. DOE variable between Iron Phosphate and Zinc Phosphate coating

| Fixed variable: material CRS, 70° temperature | Manipulated variable: time, mins | Time, mins | Coating weight of Iron Phosphate, mg/ft² | Coating weight of Zinc Phosphate, mg/ft² |
|-----------------------------------------------|----------------------------------|------------|------------------------------------------|------------------------------------------|
| 15 mins                                       | 40                               | 455        |
| 30 mins                                       | 56                               | 500        |
| 45 mins                                       | 79                               | 640        |

To strengthen the justification on mechanical properties of zinc phosphate coating, there 2 mechanical tests was conducted; Cross-Cut and Tape Adhesion (refer to standard ASTM 3359) and Impact Test (refer to standard ASTM D2794). Each test is compulsory for customer to ensure the proposal material have same properties with previous coating materials. From mechanical test Cross-
Cut and Tape Adhesion and Impact Test found there no paint peel off. This result also shows that zinc phosphate was properly adhered to substrate Figure 8.

![Figure 8. Result of Cross-Cut and Tape Adhesion (left) and Impact Test (right)](image)

Monitoring period was done from November 2020 until January 2021 and the result shows this is a proven improvement process because based on Histogram chart in Figure 9 there no rusty issue highlighted from customer and internal.

![Figure 9. Histogram chart customer and internal issue from November 2020 until January 2021](image)

4.5 Control
In this phase, in order to improve the productivity of the company Process Control Plan (PCP), FMEA was revising based on the improvement results. This document also keeps as reference for future continuous process improvement.

5. Conclusion
Lean six sigma is a technique that relies on an initiative by a cooperative team to increase efficiency by constantly minimizing waste and reducing variance. A thorough analysis of the organization starts with the report. The study was conducted based on customer and internal feedback there have a lot of issue related to rusty found in carbon steel materials. After performing proper analysis like DMAIC methodology, we found that there is an issue related to coating materials which is not suitable for complexity product. Zinc phosphate coating material was proposed to change current iron phosphate coating due to advantages of zinc phosphate have more corrosion time resistant compare to iron phosphate. Based on the analysis we have derived an action plan detailing the implementation of chosen solutions by revised PCP as a control method to ensure this document become a reference in future.

Being a sheet metal fabrication company there is a considerable scope for improving the sustainability of the system by deriving the sustainability metrics such as economic, social and environmental metrics. There have disadvantage of using Zinc Phosphate material in longer time because this is considered one of hazardous materials and need to be properly process. To broader this research study related to controlling hazardous Zinc Phosphate materials, one research study need be proposed with using any other quality control method.
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