Defect Reduction Using Six Sigma Methodology in Home Appliance Company: A Case Study

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Abstract

Six Sigma is a well-structured methodology that helps organizations to achieve their goals due to its role as a problem-solving technique. This research discusses the application of the Six Sigma methodology in home appliance industrial Company in Egypt. The paper follows the Six Sigma DMAIC methodology (Define, Measure, Analysis, Improve, and Control) to systematically identify and define the root cause(s) of defects and to provide a reliable solution to reduce/eliminate them. Moreover, the use of the design of experiment (DOE) and the regression analysis have permitted to determine any existing correlation between the measurable causes and the increase in defects quantity and to identify the optimum temperature of the aluminum molten metal. The analysis of Six Sigma (DMAIC) methodology and the statistical analysis (DOE and regression analysis) determined that the aluminum molten metal temperature has a significant impact on the defects quantity of aluminum parts. After using the optimized temperature of the aluminum molten metal, the defects in aluminum products decreased from 10.49% to 6.1% and the Six Sigma level improved from 2.8 to 3.06. Therefore, Six Sigma can be considered a successful methodology in reducing defects and consequently increasing the cost savings and customer satisfaction.

Keywords
Six Sigma, Process Improvement, and DMAIC

1. Introduction

Over the years, the Six Sigma has been adopted by many companies and successful cases are available in the literature, e.g. Motorola, General Electric, Honeywell, AlliedSignal, Raytheon, and Delphi Automotive have implemented Six Sigma programs (Treichler, et al., 2002). Six Sigma was first developed as a statistically-based technique to define measure, analyze, improve, and control (DMAIC) manufacturing processes and to reduce the variability in these processes at Motorola (Antony, et al., 2016).
This paper reports a case study of adopting Six Sigma methodology to solve the problem of the increasing aluminum defective parts in one of the well-known home appliances manufacturing companies in Egypt. The Six Sigma team

started their work by following the DMAIC phases. Defining the problem to be solved as well as identify its effects on the organization. Measuring the process performance by collecting the data and identifying the critical measures that are necessary to determine Critical to Quality (CTQ) requirements by customers. Analyzing all potential causes concentrated on the most likely root causes using cause and effect diagrams, brainstorming, and Pareto diagrams. Evaluating and selecting the right improvement solution and determining the approach to be followed using the Design of Experiment (DOE), and regression analysis. Ensure achieving the continuity of the targeted results through the use of metric measures and statistical control charts.

2. Literature Review

Sigma (σ) is a letter in the Greek alphabet that has become the statistical symbol and metric of process variation (Jirasukprasert, et al., 2014). The sigma scale of measure is perfectly correlated to such characteristics as defects-per-unit, parts-per-million defectives, and the probability of failure. Six Sigma is equal to 3.4 defects per million opportunities (DPMO) (Oakland, 2003). In order to increase the sigma level of a process, the organization must decrease the amount of variation (Nave, 2002) and make sure that the process is appropriately targeted.
Six Sigma is basically based on five phases, namely the Define, Measure, Analyze, Improve, Control (DMAIC) (Antony, et al., 2016), to achieve the organization objectives through improving the process performance and to reach high levels of quality by eliminating the root cause(s) of defects and to minimize process and product variability (Cherrafi, et al., 2016).
Define phase is concerned with defining the problem and the project scope in addition to knowing the customer needs and requirements (Antony & Banuelas, 2002; Henderson & Evans, 2000). While in the Measure phase, data can be collected and elaborated and the key process characteristics can be measured (Sokovic, et al., 2010). In the Analyze phase, the root causes of the problem can be determined (Antony & Banuelas, 2002), the experiments and statistical technique can be conducted (Tong, et al., 2004). The Improve phase is dedicated to generating improvement opportunities and select the most appropriate in order to reduce/eliminate defects. The control phase focuses on ensuring that the improvements are maintained (Antony & Coronado, 2002) and prevent the process performance not to go back.
Six Sigma has two philosophies according to the status of the process. The DMADV (Define-Measure-Analyze-Design-Verify) or DFSS (design for Six Sigma) exploited in designing new processes, products, and service (Sung, 2003). The DMAIC, which is a systematic procedure (Chakravorty, 2009), is used to incrementally improve existing processes targeting overall improved organization's processes, products and services. The former philosophy will not be discussed nor implemented in this study.
There are many benefits of implementing Six Sigma and using its associated methods, briefly described in the following (Zu, et al., 2008):

- Having a measurable way to track performance improvements;
- Focusing the attention on process management at all organizational levels;
- Improving the customer relationships by addressing the defects;
- Improving the efficiency and effectiveness of the processes by aligning them with the customers' needs;
- Developing new processes, products, and services that meet critical customer requirements.

The DMAIC method is very robust and has been successfully used by many organizations to produce dramatic improvements. One of Six Sigma's distinctive approaches to problem-solving and improvement is measurement system analysis (Antony & Banuelas, 2002), which is essential for organizations as it permits to measure, monitor and evaluate the performance in a continuous manner. However, in order to ensure successful data analyses, at all stages and processes, effective data gathering processes are crucial (Sagnak & Kazancoglu, 2016).
The home appliances market is a fast-growing market in Egypt. Also, the competition is fierce between the companies working in this sector due to the increasing customer needs (Seleem, et al., 2016). Hence, the studied organization started to engage in continuous improvement projects such as Six Sigma in its strategy to satisfy its customers. Home appliances manufacturing involves many processes, e.g. the raw material selection, aluminum injection, quality control, finishing, sanding, and the final product storing. There are many defects that may be produced in these processes such as die-casting and aluminum injection defects (e.g., injection reduction, scratches and cracks, and leakage), finishing (e.g., injector leakage and steps defects), and sanding defects. Every process must be continuously monitored and controlled to prevent producing defective products. Accordingly, the Six Sigma project is used, on the one hand, to reduce/eliminate defects and, on the other hand, to increase the customer's satisfaction (Seleem, et al., 2016).

3. Methodology

In our case study, the Six Sigma and DMAIC methodology have been applied in order to identify the existing problem, determine the root causes of the problem, and to set the appropriate solutions to reduce/eliminate them. According to DMAIC methodology which this paper is following, first, the problem was defined. Then, adequate data were collected to measure the process performance and identify the Critical to Quality (CTQ) requirements. All potential causes, concentrated on the most likely root causes, were analyzed using the cause and effect diagram and also the Pareto diagram. After that, several improvement solutions were evaluated using design of experiment and regression analysis techniques and the best solution was selected. Also, the right approach to be taken to assure achieving the continuity of the targeted results is determined. Finally, suitable procedures have been implemented to ensure maintaining the obtained improvements and not allowing the process performance to go back.

4. Case Study

4.1 Define Phase

The case study, the home appliance company, was suffering from increasing the defects quantity, customer complaints, and the cost of bad quality as a result of rework and scrap material. Also, such problems had serious effects on the production processes such as enlarging the production cycle time, disturbing the process in several departments, and not fulfilling the delivery time's commitment to customers. Therefore, the company adopted the Six Sigma methodology to resolve these problems, gain customer satisfaction, and make cost savings, by improving the sigma levels of the production processes.
First of all, all the efforts were concerned with defining the problem and identifying the departments that contribute the most to the problem. Hence, the project selection matrix, reported in Table 1, was used to define the involved departments. A total number of 5 departments were involved, namely the Aluminum, Zamak, Copper, Thermoset, and Thermo Plastic sections.

4.1.1 Project Selection Matrix

Based on the project selection matrix (Table 1) and the primary collected data, the aluminum department was chosen, as a pilot for the application of the Six Sigma, because it had the highest impact on the improvement project. Moreover, it has the highest percentage and contributes the most to the total amount of rejected parts as discussed in the Measure phase section 4.2. Therefore, by improving the processes of the aluminum department, the one would have sensible contributions to solving the problem.

Table 1: Project selection matrix.

		Impact						**Effort**					
Serial	**Opportunity/ project description**	**Customer**	**Cost**	**On time delivery**	**Quality**	**Replication**	**Total impact**	**Personnel/man need**	**Complexity**	**Resistance**	**Risk**	**Total effort**	**Impact/Effort**
	Variable weightings	**0.28**	**0.25**	**0.2**	**0.22**	**0.05**	**1**	**0.25**	**0.3**	**0.2**	**0.25**	**1**	
1	Aluminum defect reduction	3	5	3	5	5	4.04	3	5	3	5	4.1	0.99
2	Zamak defects reduction	3	3	3	5	5	3.54	3	3	3	5	3.5	1.01
3	Cupper defects reduction	3	5	3	3	5	3.6	5	3	3	3	3.5	1.03
4	Backlight defects reduction	1	3	3	5	5	2.98	3	5	3	1	3.1	0.96
5	Plastic defects reduction	3	3	5	3	5	3.5	3	5	1	1	2.7	1.3

Where the reported values are divided into 4 categories as follows: 0 means NA, 1 means low, 3 means medium, and 5 is high.

4.1.2 Voice of Customer "VOC" & Critical to Quality "CTQ"

Because listening to the customer is a key factor for a successful business, the voice of the customers (VOC) was addressed in this project in order to be familiar with the customer needs and requirements (Antony, et al., 2002). The VOC was then translated to the characteristics critical to quality (CTQ) that can be easily measured so that the team can set the objective of the Six Sigma project (Henderson, et al., 2000).

4.2 Measure Phase

The data was collected on the amount of rejected aluminum parts in the different aluminum department processes over a time span on 12 months, from January 2016 till December 2016. The amount of the rejected parts in kilograms was calculated as the shown below in Figure 1. In order to calculate the Sigma level we first calculated the production processes Yield which means the percentage of free of defect output.

Yield = 1- The proportion defective = 1- (Total amount of defective parts/ Total input amount)

From the gathered data; the total amount of defective aluminum parts = 88.18032 Ton and the total amount of aluminum input into different process = 840.3042 Ton.
Yield = 1- (88.18032 / 840.3042) = 0.895*100= 89.5%
After that, the Yield percentage was converted into Sigma level using the Yield to Sigma level conversion tables and the obtained Sigma level is 2.8.

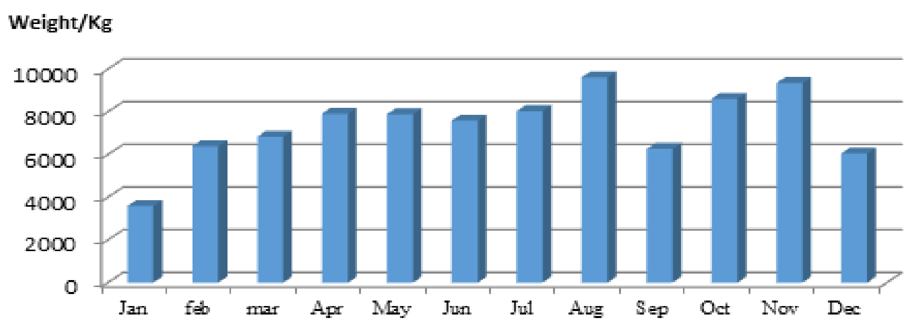

Figure 1: Aluminum rejected quantity for 12 months.

4.3 Analyze Phase

The analyze phase of the DMAIC methodology is concerned with analyzing the manufacturing processes, the aluminum department processes in this case study. This phase aims to identify the root causes of the problem through using many tools such as brainstorming, process mapping, cause and effect diagrams, DOE, hypothesis testing, statistical quality control and simulation (Jirasukprasert, et al., 2014). This research used brainstorming, cause and effect diagrams, and Pareto diagrams as illustrated in details in the following steps:

1. Step 1: The cause and effect diagram, as shown in Figure 2, was drawn in order to identify the possible causes of the problem. The parameters of aluminum parts rejection are the operator, machines, material, furnace, die, and working environment.
2. Step 2: After identifying all the possible causes of aluminum rejection, the aluminum rejection parts were thoroughly studied. It was found that the major rejection parts consist of four products, the rear base, upper base B, sabaf base 60, and sabaf base 90.
3. Step 3: The historical data, collected for a period of 12 months on the causes of the rejected parts, were deeply investigated. These data contain information on the amounts of all of the production, defective parts, and rejection due to different types of defects such as leakage, injection reduction, cracks and scratches and many other types. The Pareto diagrams were drawn, in order to prioritize the major causes of rejection as shown in Figure 3. From the Pareto diagrams, it was found that injection reduction and leakage were the major causes of the products rejection.

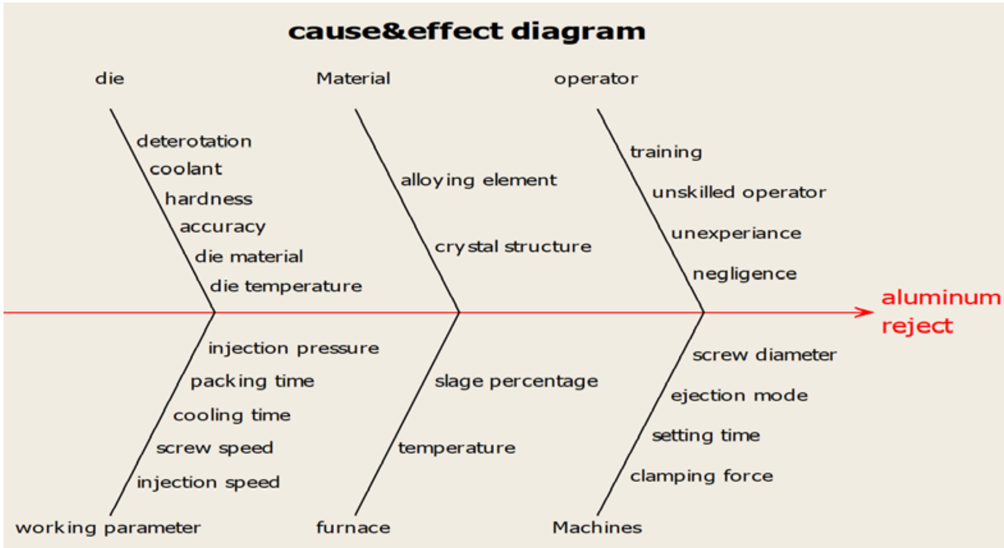

Figure 2: Cause and effect diagram of aluminum rejection.

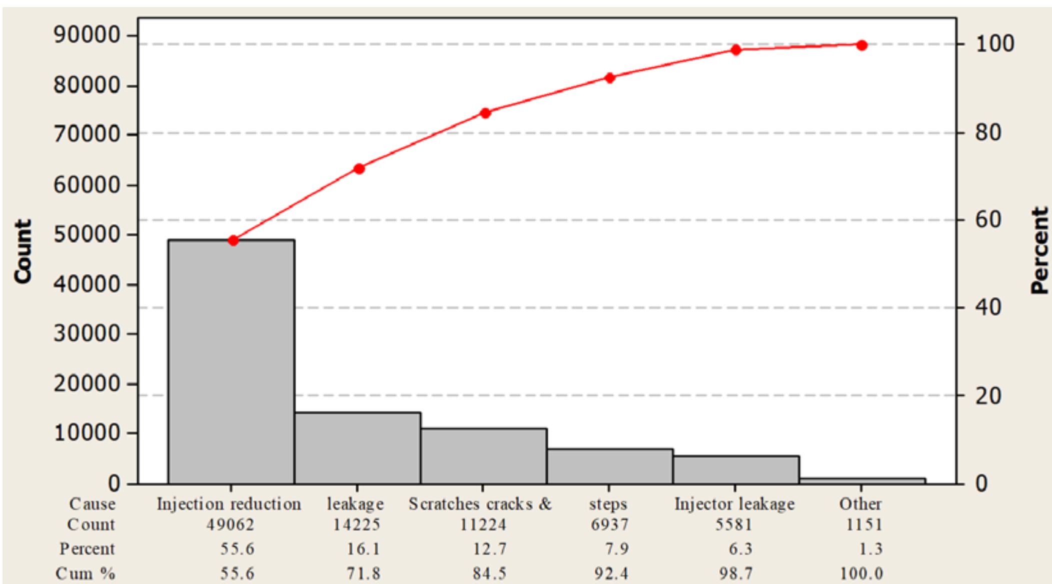

Figure 3: Pareto diagram of aluminum rejection causes.

4. Step 4: One more time, the cause and effect diagrams were drawn to determine the causes of the injection leakage and reduction, as shown in Figure 4 and Figure 5, respectively.

4.4 Improve Phase

The goal of the Improve phase is to develop, try out, and implement solutions that address root causes and use data to evaluate the solutions as well as the executed plans. The main output of this step includes:

- Planned and tested actions that eliminate or reduce the impact of the identified root cause(s);
- “Before” and “after” data analysis that shows the gained improvement of the initial gap;
- A comparison between the synthetic plan and the actual implementation.

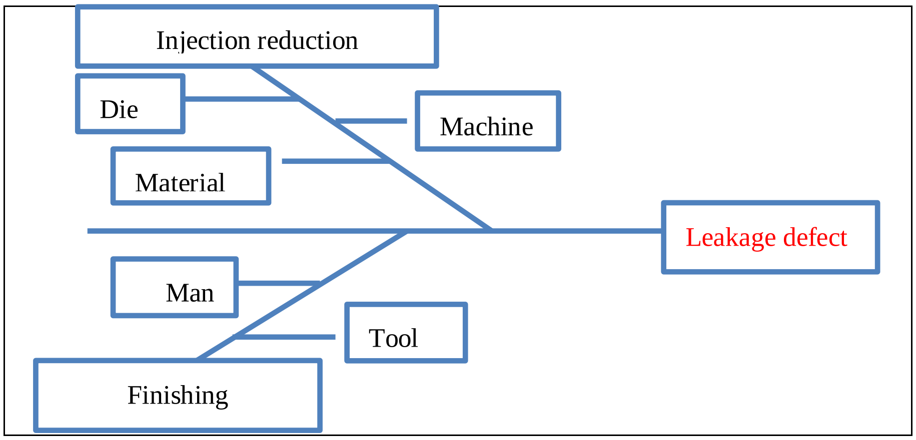

Figure 4: Cause and effect diagram for the leakage defect.

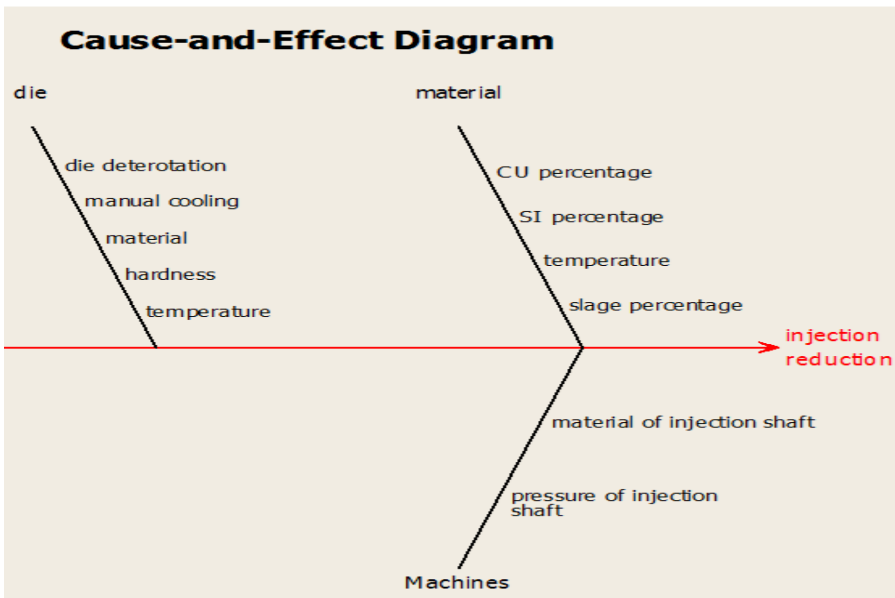

Figure 5: Cause and effect diagram of the injection reduction.

4.4.1 Regression Analysis

After identifying the possible causes of the major defects in the analyze phase, the regression analysis was carried out to determine the correlation between these causes and the increasing number of the rejected parts. From the cause and effect diagrams, the measurable factors of identified causes are:

- Temperature;
- Pressure;
- Cooling time;
- Cu percentage;
- Si percentage.

From the available statistical information on the aluminum production processes, a total number of 20 samples were selected as the suitable sample number to be tested. The samples, of each product type, i.e. rear base, upper base B, sabaf base 60, and sabaf base 90, were checked and all main measurable factors, i.e. temperature, pressure, cooling time, Cu percentage, and Si percentage were precisely measured in order to identify the significant factors. Table 2 and Table 3 document the collected data related to the measurable factors affecting rear base products defects and the regression analysis results.

Table 2: The collected data of the measurable factors affecting rear base product defects.

Sample	Temperature	Cooling time	Pressure	Cu %	Si%	Defect percentage
1	630.4	12.026	150	2.59	12.26	30
2	650.2	14.96	150	2.04	13.31	32.5
3	650	14.19	154	2.06	14.1	7.5
4	647	13.7	152	1.22	13.82	12.5
5	638	14.18	150	1.5	13.75	25
6	636.8	10.18	151	2.3	11.33	32.5
7	637.7	13.066	151	2	12.56	17.5
8	640.8	13.3728	151	1	13.8	20
9	649	12.2069	152	1.97	11.63	15
10	657	15.09	151	2.39	11.01	10
11	654	14.9321	153	2.08	10.52	20
12	645	13.4412	151	1.74	13.45	30
13	639.8	15.74	151	1.74	13.45	22.5
14	632.5	13.082	152	2.53	13.96	25
15	622.6	14.881	153	1.93	12.04	100
16	617	14.19	154	2.13	14.37	100
17	654	12.472	150	1.25	13.95	15
18	652.5	14.256	152	1.62	10.22	5
19	647.6	14.69	151	1.45	13.6	20
20	644.6	14.5	150	2.3	11.9	12.5

The regression equation used is:

Defects percentage = 133 - 1.74 Temperature - 0.232 time + 6.79 pressure - 3.04 CU% - 0.35 SI%

Table 3: Rear base regression analysis results.

Predictor	Coef.	SE Coef.	T	P
Constant	132.9000	832.9000	0.16	0.875
Temperature	-1.7426	0.4998	-3.49	0.004
Cooling Time	-0.2317	0.2364	-0.98	0.344
Pressure	6.7920	3.8020	1.79	0.096
CU %	-3.0410	9.8970	-0.31	0.763
SI%	-0.3550	4.0250	-0.09	0.931

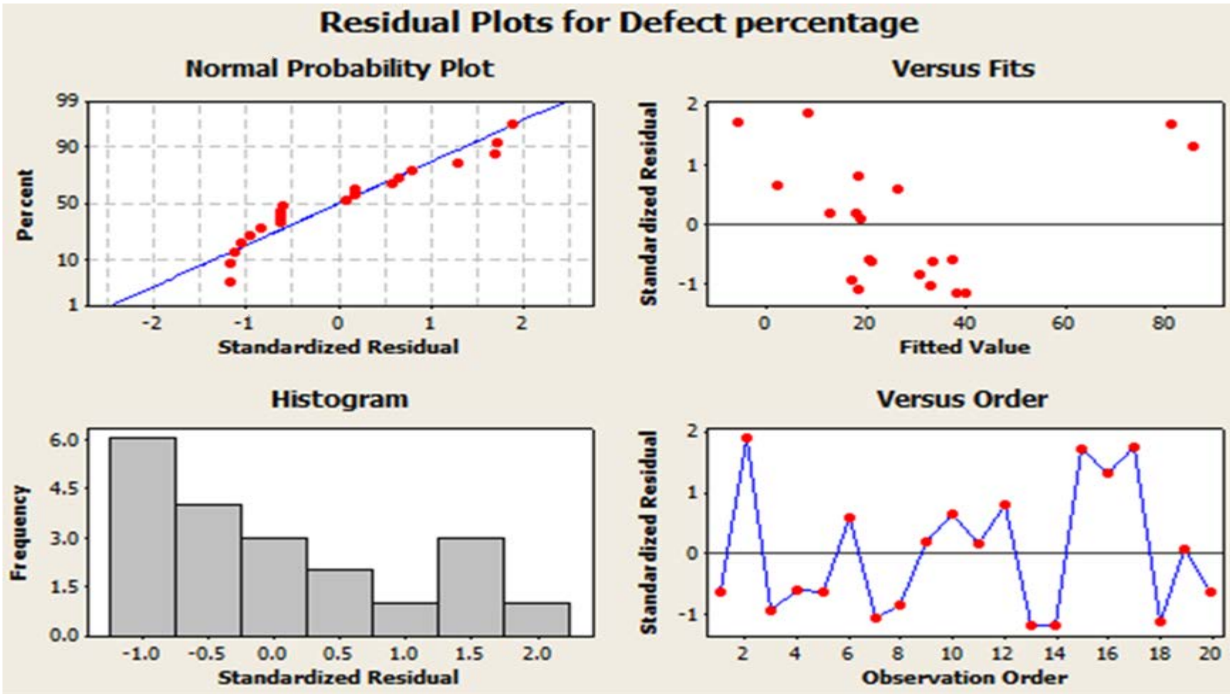

Figure 6: Regression analysis results.

From the regression analysis results reported in Table 3 and Figure 6, it is noticeable that when P value of the test is less than 0.005, the temperature factor is the significant factor that affects the defects percentage. Also, it has been found that when the temperature decreases, the aluminum defects percentage increase, which could be explained as the temperature variation due to directly adding scrap to the furnace, leads to temperature decrease. In order to solve this problem, the DOE method was exploited to identify the best working conditions to ensure maintaining the appropriate temperature to reduce the defects quantity. In this experiment, the simulation for the furnace used to melt aluminum material was built keeping the temperature between 700°C to 750°C. Then, the molten material is moved to the machine furnace to decrease slag while prohibiting the labor from adding any scrap to the molten metal.

It was found that the use of a separated furnace from the machine furnace while raising the temperature of the molten metal to 750° C and reducing the percentage of the added slag has produced the best results in reducing the defects quantity.

4.5 Control Phase

The goal of the Control phase is to maintain the obtained gains by standardizing the work methods and/or processes, anticipating future improvements, and to ensure that the improved processes have remained in-control (Jirasukprasert, et al., 2014). This project used a controllable gauge to alarm when the furnace temperature decreases below 750°C in order to prevent producing any defective aluminum parts and, on the meanwhile, to maintain operating under the optimal the furnace temperature (750°C).

Also, the gauge is set to alarm when the furnace temperature increase above 750 °C, because the molten material may adhere to the plunger, in addition, the plunger of the machine cannot stand with such a high-temperature. Furthermore, control charts were exploited to detect any abnormalities in the processes (Snee, 2004) to prevent the improved processes to go back and to the appropriate action needed. The variable control charts (X and R control charts) were implemented to monitor the defective aluminum parts percentage.

Table 4: Six Sigma improvement results.

	Before improvement		**After improvement**	
Name	**Yield**	**Sigma level**	**Yield**	**Sigma level**
Upper base sabaf 60	84.11	2.54	95	3.14
Rear base	76.69	2.20	93	2.98
Upper base B	84.49	2.54	94	3.05

5. Conclusion

The work presented in this paper shows that the Six Sigma is an efficient and a successful problem-solving methodology. Using Six Sigma and the DMAIC methodology in this home appliances company have reduced the quantity of aluminum defective parts, which will have great consequences for both the customer's satisfaction and cost savings.

The analysis conducted in the Analyze phase illustrated that the problem of increasing aluminum rejection quantity occurred due to two main types of defects (leakage and aluminum reduction). The in-depth analysis identified that the temperature has a significant impact on producing these two types of defects. Hence, the problem was solved and the reduction of aluminum defects quantity was achieved by identifying the optimal furnace temperature, which is found to be equivalent to 750°C. By working under such optimal temperature, the aluminum rejected quantities was decreased from 10.49% to 6.1% and the Six Sigma level was improved from 2.8 to 3.06. Although the Six Sigma concept was improved to 3.06, in a time-consuming process takes a lot of time, the results are considered a good achievement.

In the end, Six Sigma projects are based on incremental and continuous improvement concept and by exploiting the Six Sigma methodology, organizations can achieve their goals and gain great benefits of customer satisfaction and cost savings.

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Biography

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