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Aluminium hot extrusion process capability improvement using Six Sigma

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A B S T R A C T

In this work, the Six Sigma (Define-Measure-Analyse-Improve-Control) DMAIC methodology has been followed to explain the original problem of lowering extrusion process variation and improving the process capability based on the determined Critical Quality Characteristics (CQC). The extrusion process charter worksheet is recognized, a SIPOC (Supplier-Input-Process-Output-Customer) chart is constructed and a Pareto chart is drawn in the Define phase of the methodology. Measurement data are collected, verifying process stability and verifying process normality by using $\bar{X}$-R charts and normality test, respectively. Process capacity index, sigma levels, defects per million opportunities (DPMO) determination in the measure phase using a Histogram. During Analyse phase, Cause and Effect diagram are established to determine their likelihood for the root cause of aluminium extrusion defective products. The suggested solutions are installed in the improve phase. In the Control phase, all tools are applied in the Measure phase are repeated to determine the improvement level. The DMAIC methodology has been applied in the (Ur state company for engineering industries)/(aluminium extrusion factory). The Minitab 16 Software is used for calculations and plot charts. The results for the internal dimension (X1) of the corner section product indicate a reduction in DPMO from 536804 to 185795.09, sigma level is improved from 1.4 to 2.4, process yield (Y) is improved from 46 % to 81 %, and profit is improved from ID 127.000 to ID 223.000 per 1000 kg.

A R T I C L E I N F O

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1. Introduction

Six Sigma was used by Motorola in 1987 [1]. Therefore of a series of changes in the quality area beginning in the late 1970s, with determined ten-fold advance drives [2]. The top-level organization management along with CEO Robert Galvin developed a theory called Six Sigma [3, 4]. From 1987 to 1997, Motorola got a fivefold increase in sales with income climbing nearly 20 percent per year, cumulative investments at $14 billion and stock price gain compounded to a once a year rate of 21.3 % [5].

In 1994, Six Sigma was started as a business initiative to produce high-level results, improve work processes, expand all employees' skills and change the culture [6]. GE determined in 1995 to apply Six Sigma throughout the entire companies. CEO Jack Welch led the organization during this implementation, and many distributions of GE experienced notable improvements in quality through those years [7]. Universal Electric reported that $300 million supplied in 1997 in Six Sigma send between $400 million and $500 million savings, with further incremental limits of $100 million to $200 million [8, 9].

In early 1997, Samsung and LG set in Korea started to establish Six Sigma under their comp organizations. The outcomes were surprisingly good in those organizations. For example, Samsung SDI, which is an organization under Samsung set, reported that the cost investments by Six Sigma planner totalled $150 million [10, 11]. Sigma is the letter in the Greek alphabet utilized to indicate standard deviation, a statistical mensuration of variation, the exclusion to expected results. The standard deviation can be thought of like a comparison among expected results in a group of procedures, against those that not succeed. The measurement of standard deviation illustrates that rates of defects, or exceptions, are calculable [7, 12]. Six Sigma is arithmetical term that refers to 3.4 defects per million (or 99.99966 % accuracy), which is as close as anyone is probable to obtain to perfect [5, 13]. A defect any effect that falls short of the customer's requirements or expectations [7].

Six Sigma methods use defects per unit (DPU) like a measurement tool. DPU is a good method to determine the quality of product or a process. The defects are generally relation between the time and the cost. The sigma value additional shows the frequency at which failures happen; as a result, as upper sigma value means the lower defect possibility. The defect is definite as the displeasure of the customer. Therefore, as sigma level raises, cycle time and cost reduce and at the same time customer satisfaction raises [6].

In Six Sigma method there are two tools namely: DMAIC and DFSS. The overall method to solve problem by DMAIC method consist of: translation of a practical problem into a statistical problem, discover a statistical solution, and then translation of that statistical solution into a practical solution and implementation appropriately in the industry [14].

Gijo et al. [15] shows the application of the Six Sigma method in decreasing defects in a fine grinding process of an automotive company, The DMAIC (Define-Measure-Analyse-Improve-Control) method to solve the original problem of decreasing process improving and variation the process yield. The purpose of the Six Sigma method resulted in decrease of defects in the fine grinding process from 16.6 % to 1.19 %.

Hung et al. [16] showed how a food company in Taiwan can use a systematic and disciplined method to go towards the aim of Six Sigma quality level. The DMAIC phases are used to reduce the defect rate of small custard buns by 70 % from the baseline to its entitlement. After the development actions were implemented through a six-month period this fell to under 0.141 %. Mandahawi et al. [17] studies a procedure development study applied at a local paper manufacturing support on customized lean Six Sigma method. The DMAIC methodology and various lean tools are used to streamline processes and enhance production. Gupta [18] showed a quality development study applied at a yarn manufacturing company's foundation on Six Sigma methodologies. The DMAIC task management-methodology and various tools are used to streamline processes and enhance production. Defects rate of textile goods in the yarn manufacturing process is so essential in industry point of view.

2. DMAIC methodology phases application

DMAIC is closed-loop method that removes non-productive steps, oftentimes concentrate on new measurements, and used technology for continuous development. Achievement of DMAIC method took place in five phases. Problem classification and definition takes in defining phase. After recognizing main processes, their performance is determined by measure phase with the assist of data collection. Origin causes of the problem are establishing out in the analysis phase. Solutions to implement problem and solving them are in improving phase. Development is maintained in control phase. The following case is taken from production line that produces aluminium products in in the (Ur state company for engineering industries) and particularly to (aluminium extrusion factory) [14].

2.1 Define phase

Define the extrusion process at dissimilar angles with the help of tools as the extrusion process charter worksheet and Pareto chart as shown below.

Drafting the extrusion process charter worksheet

This extrusion process charter worksheet outlines the purpose, objectives, and scope of the project as shown in Table 1.

Table 1 Extrusion process worksheet

Project title	Extrusion process capability improvement using Six Sigma
Business case	Extrusion factory in Ur state company for engineering industries produces varying amounts of typical aluminium products. Depending on the data recorded for the marketing department as shown in Table 2. It illustrates the increase of defects percentage due to the appearance of defects in products so that the records for the year 2012 will be taking due to the lack of the production rate.
Problem statement	Appearance defects in aluminium products and this has led to lower production rate as shown in the Table 2.
Goal statement	Improve extrusion process capability to reduce extrusion defects that appear frequently and in large quantities in the typically aluminium products, increase production costs, reduce inventory planes, raise profit and get better satisfaction for customer.

Table 2 Sales of aluminium products for years 2010 to 2012

Year	Production quantity (× 1000 kg)	Production sold (× 1000 kg)	Production defective (%)	Annual income (× ID 1000)
2010	67.837	60.836	10	270.325
2011	92.342	82.854	10.5	365.000
2012	313.005	268.501	14	1.182.00

Developing process map (SIPOC Diagram)

The SIPOC diagram of this work describing the supplier, input, process, output and customer are as shown in Table 3.

Table 3 Supplier-Input-Process-Output-Customer (SIPOC) diagram

Supplier	Input	Process	Output	Customer
1 – Raw material store 2 – Dies store 3 – Adjuvants store (Graphite pens) 4 – Sutton company	1 – Aluminum alloy 6063. – Dimensions (Billet diameter ø178-198 mm and length L 400-700 mm) – Standard specification (ASTM-B221 Iraqi standard 1730) 2 – Physical properties 3 – Chemical composition 4 – Hydraulic fluid	1 – Preheating process 2 – Extrusion process 3 – Quenching process 4 – Stretching process 5 – Cut-off process 6 – Artificial aging 7 – Packaging process	1 – Square section 2 – Rectangular section 3 – Joint section 4 –Swing doors section 5 – Structural section 6 – Furniture section 7 –T-section 8 – Angles section 9 – Round section 10 – Corner section	1 – Directorate General of Electricity Distribution Rusafa 2 – Directorate General of Electricity Distribution Karkh 3 – Directorate General of Electricity Distribution Euphrates 4 – Directorate General of Electricity Distribution South 5 – Directorate General of Electricity Distribution center 6 – Directorate General for power

Project selection

In this step the aluminium products and extrusion defects are selected and by using the data in the records of quality control department in extrusion factory for the year 2012. Initially, Pareto chart in Fig. 1 should be used to select only the vital aluminium products that have the highest cumulative percentage as a key product. Finally, Pareto chart in Fig. 2 should be used to select only the vital extrusion defects that have the highest cumulative percentage as a key defect.

According to results from the Pareto charts in Fig. 1 and Fig. 2, the corner section product has the polygon with high defective rate (0.32) with percent (17.8), and the dimensional deflection defect has the high defective count (19923) with percent (45.2), respectively.

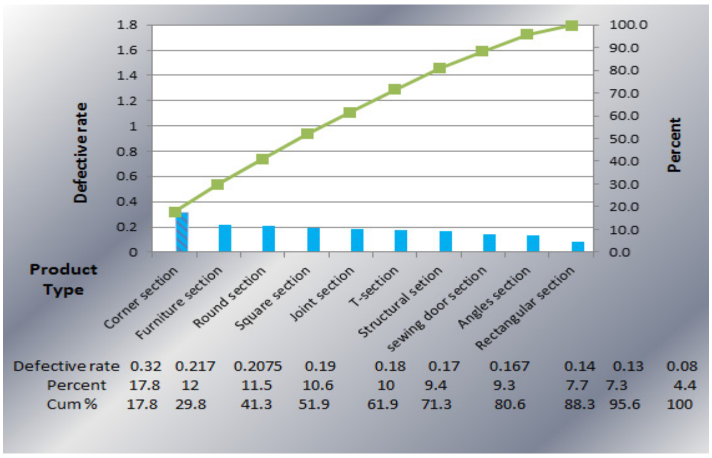


Fig. 1 Pareto chart of aluminium product type

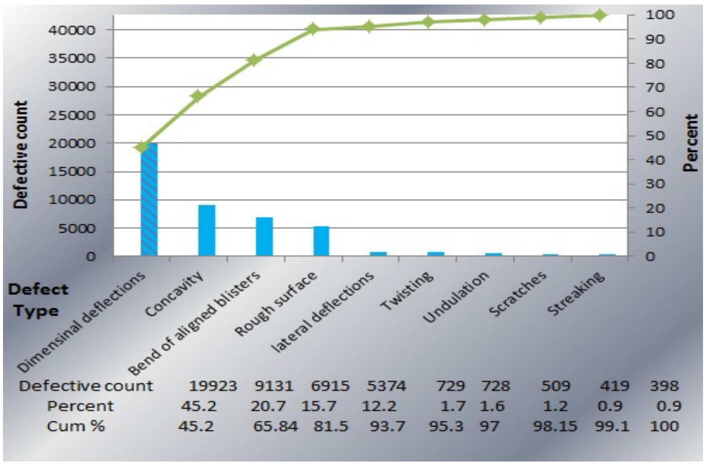
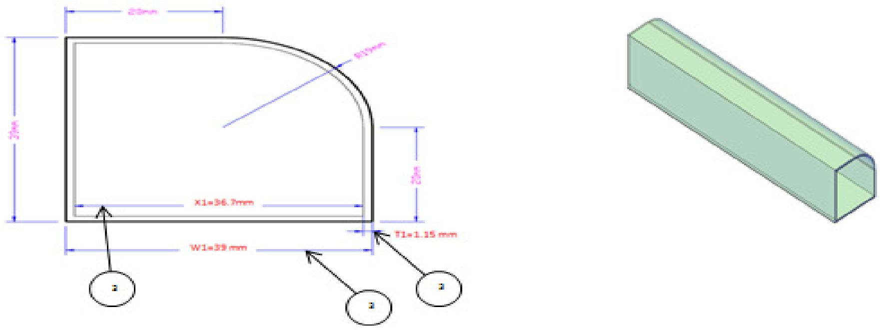


Fig. 2 Pareto chart of defect type

2.2 Measure phase

In this phase, corner section product is selected to execute the research methodology based on the results of Pareto charts in the previous phase. Critical Quality Characteristic (X1) with dimension specification ($36.7^{\pm 0.46}$) for corner section product in Fig. 3 is selected, due to its importance. Since any deviation from the required specification of (X1) will lead to the emergence of more defect products rejected by the customer. Measurements of 15 samples have been taken, each sample consist of 5 items from the packaging operation.



No.	Characteristics name	Signs	Tolerances (mm)
1	Section width	W1	$39^{\pm 0.54}$
2	The internal dimension of the section	X1	$36.7^{\pm 0.38}$
3	Section thickness	T1	$1.15^{\pm 0.17}$

Fig. 3 Corner section of the product

Analyzing the samples data by $\overline{X}$-R charts to determine if the extrusion process is under statistical control or not. Minitab 16 software is used to draw $\overline{X}$-R charts as shown in Fig. 4.

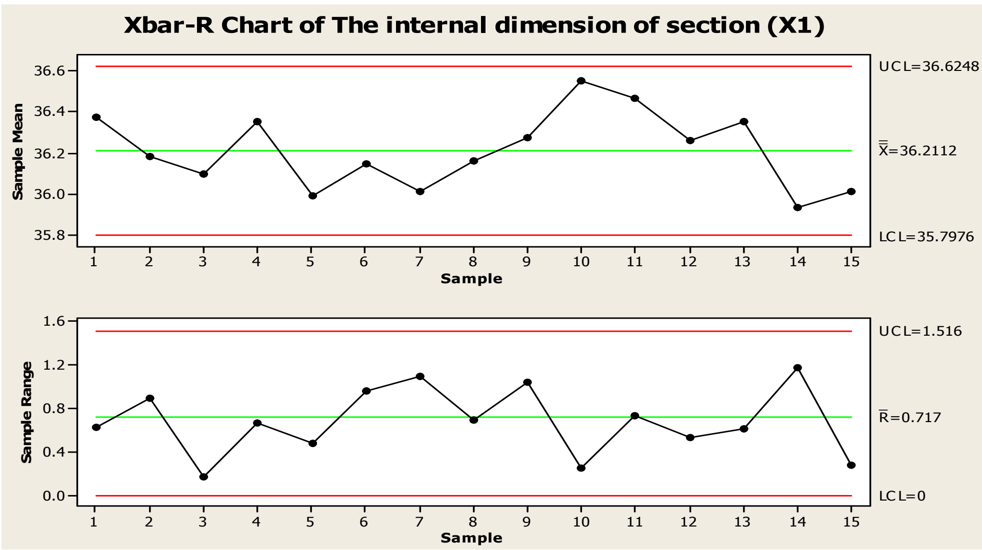


Fig. 4 $\overline{\mathbf{X}}$-R charts for internal dimension of section (X1) before improvement

In Fig. 4 we can notice internal dimension (X1) of corner section product in stable state because no points out of the control limits of $\overline{\mathbf{X}}$-R charts.

The Anderson-Darling test is used to determine the normality of internal dimension (X1) samples data of corner section product. Minitab 16 software is used for this purpose and the results are shown in Fig. 5. It is appear that (X1) samples data is normally distributed because the P-value of 0.212 is bigger than the critical value of 0.05.

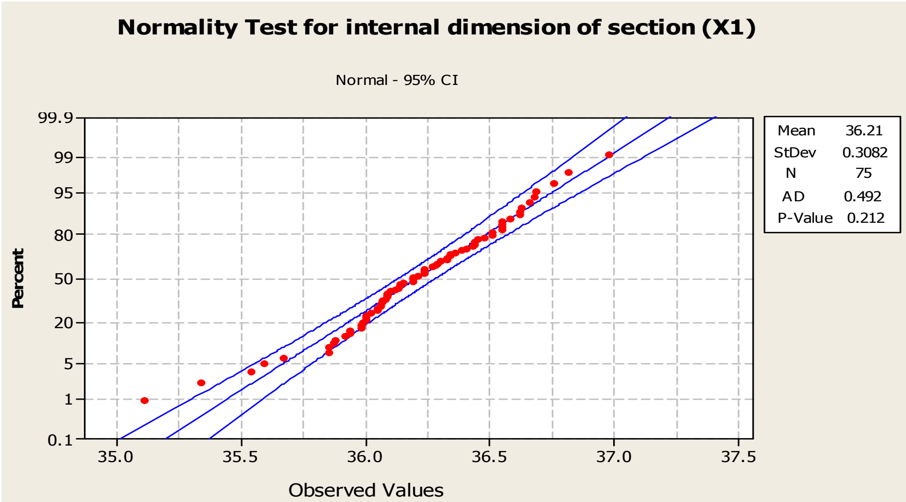


Fig. 5 Normality test for internal dimension of section (X1) before improvement

Based on the results of normality test, it is found that data for X1 are normally distributed. Therefore, process capability can be measured by using process capability analysis using histogram as shown in Fig. 6. Sigma level, yield (Y), defects per 1000 kg, and profit can be calculated by using following equations and the results in Table 4 as follows [2]:

$$\text{Sigma level} = 3 \cdot Cpk + 1.5 \tag{1}$$

$$Y = e^{-DPMO} \tag{2}$$

$$\text{Defects per 1000 kg} = DPMO \cdot W \tag{3}$$

$$W = V \cdot \rho \tag{4}$$

$$V = A \cdot L \tag{5}$$

$$\text{Profit} = (1 - \text{Defects per 1000 kg}) \cdot \text{Profit margin} \tag{6}$$

L is length of corner section product (6 m), A is area of corner section product (165 mm^2), V is volume of corner section product, W is weight of corner section product, ρ is alloys 6063 density (2685 kg/m^3), $DPMO$ is defects per million opportunities, and profit margin is ID 275.000.

Table 4 Results for calculations extrusion process measures of internal dimension (X1) of corner section of the product before improvement

Extrusion process measures	Measure value
C_p	0.46
C_{pk}	-0.03
Sigma level	1.4
DPMO	536804
Yield (Y)	46 %
Defects per 1000 kg	0.536804
Profit per 1000 kg	ID 127.000
Σ	0.329759
$\overline{X}$	36.2112

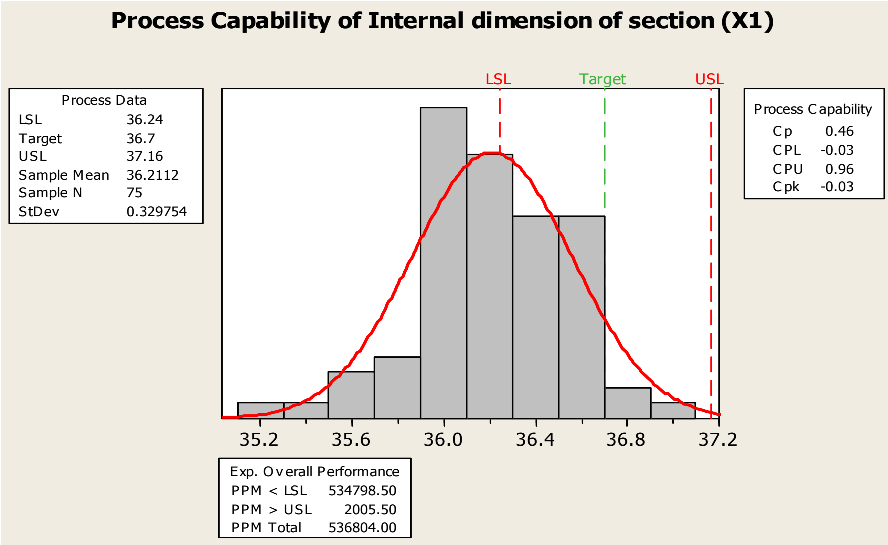


Fig. 6 Process capability of internal dimension of section (X1) before improvement

2.3. Analysis phase

This phase includes causes and effect diagram tool for analysis the previous results obtained from measure phase.

Cause and effect analysis

This step expresses the possible causes identified which have the most impact on the extrusion process. Fig. 7 for dimensional deflection defect presents a chain of causes and effects.

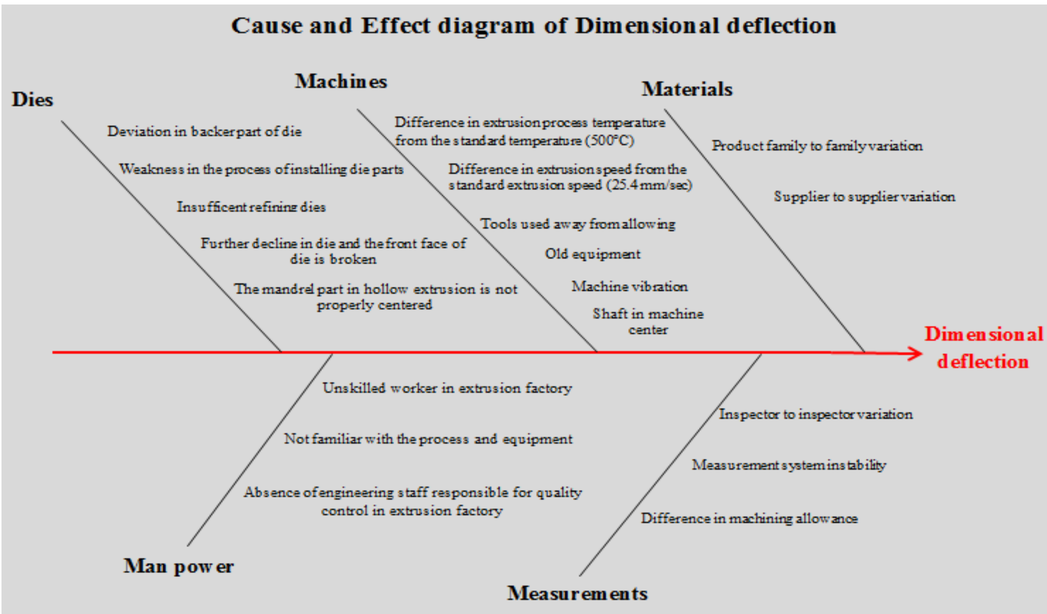


Fig. 7 Process capability of internal dimension of section (X1) before improvement

2.4 Improve phase

The improve phase is the fourth step in DMAIC methodology phases and its objective is to implement and find measures that would solve the aluminium products defects. Cause and suggested solution are shown in Table 5.

Table 5 Cause and suggested solution

Cause	Suggested solution
1 – Difference in extrusion process temperature from the standard temperature. 2 – Unskilled workers in extrusion factory. 3 – Absence of engineering staff to monitor the production line in every step of the extrusion process. 4 – Further decline in die and the front face of die is broken. 5 – Deviation in backer. 6 – Weakness in the process of assembly die parts. 7 – Insufficient refining dies.	1 – Monitoring the extrusion process temperature (control the die temperature and billet preheating temperature) by thermocouple device as shown in Fig. 8. 2 – Workers must engage in training sessions before overseeing the extrusion process. 3 – Creating a staff of quality control specialist. 4 – Replacement of the old die with a new die and check the front face of the die. 5 – Checking the process of assembly and grinding of die parts (mandrel and backer) as shown in Fig. 9, Fig. 10, and Fig. 11.

Fig. 8 Thermocouple device

Fig. 9 Parts of corner section die

Fig. 10 Corner section die after assembly

Fig. 11 Corner section die after grinding process

2.5 Control phase

The extrusion process will be test by finding the values of PCIs (Process capability indices), Sigma level, DPMO, Yield (Y) and profit after improvement. Therefore, new data of 15 samples with sample size 5 have been collected from the aluminium extrusion process. Then the entire steps in measure phase are repeated. The collected data and the details of the steps and calculations are shown in Table 6 and Figs. 12, 13, and 14.

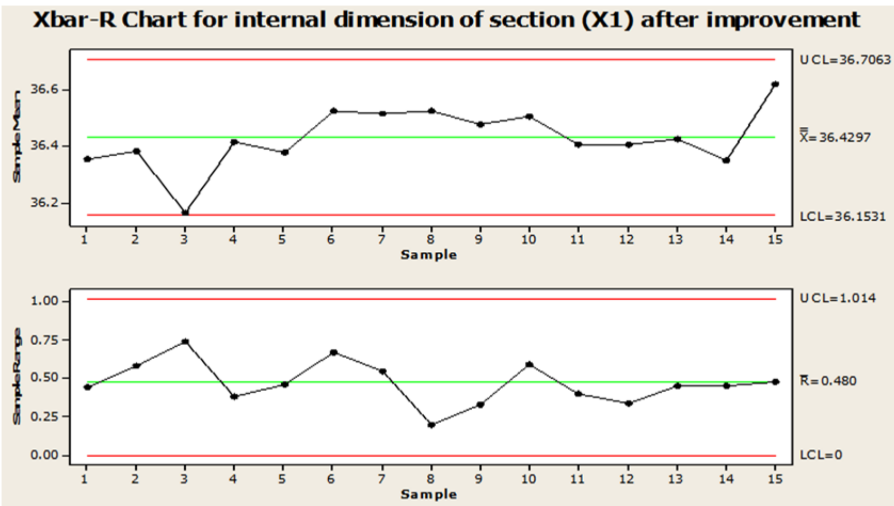


Fig. 12 $\bar{\mathbf{X}}$-R charts for internal dimension of section (X1) after improvement

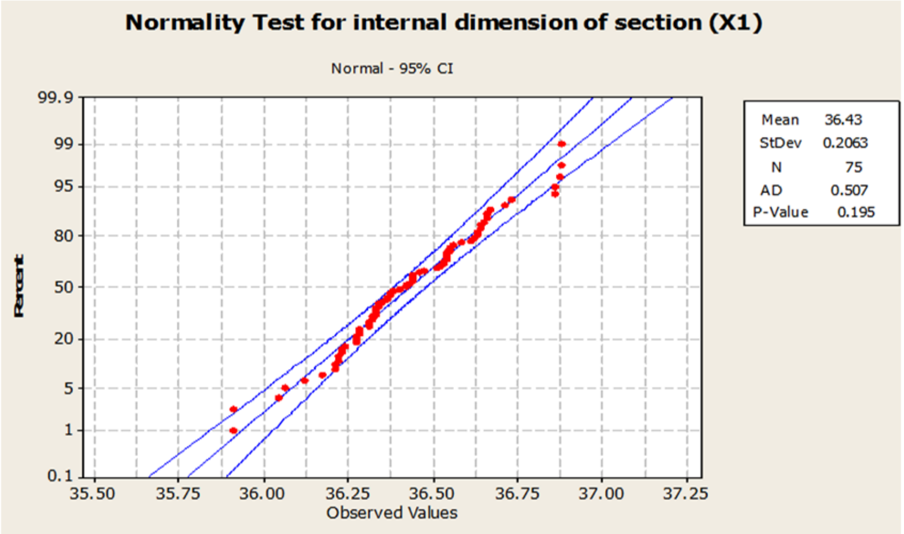


Fig 13 Normality test for internal dimension of section (X1) after improvement

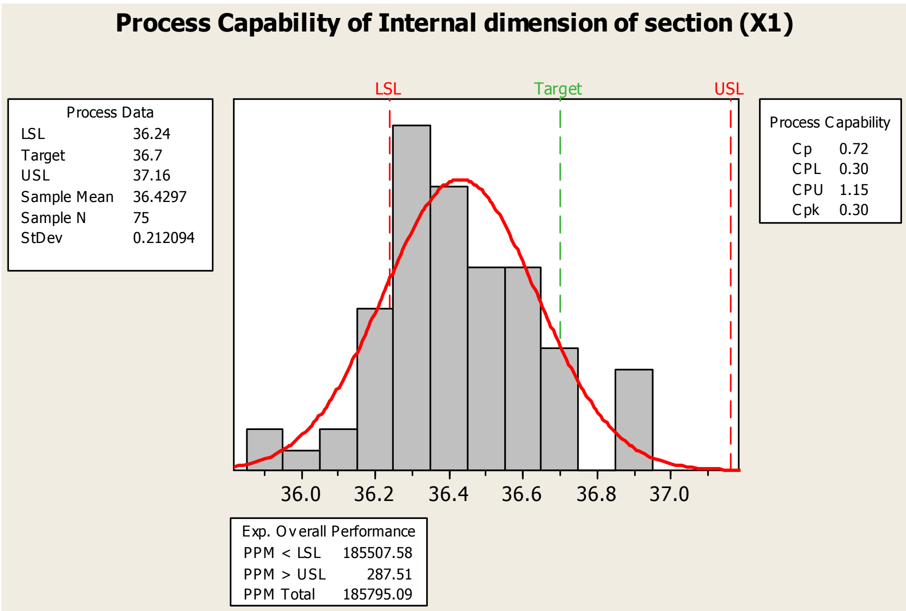


Fig 14 Process capability of internal dimension of section (X1) after improvement

Table 6 Results for calculations extrusion process measures of internal dimension of section (X1) after improvement

Extrusion process measures	Measure value
C_p	0.72
C_{pk}	0.3
Sigma level	2.4
DPMO	185795.09
Yield (Y)	81 %
Defect per 1000 kg	0.18579509
Profit per 1000 kg	223.000
Σ	0.212094
$\bar{X}$	36.4297

3. Results and discussion

The results of extrusion process measures PCIs (Process capability indices), sigma levels, and DPMO values before and after improvement shown in Table 4 and Table 6. The improvement of performance measures are as following: C_p value has been increased from 0.5 to 0.74 which means that the process capability is sufficient and the specification width greater than the process spread. The value of C_{pk} has increased from –0.032 to 0.306 which means that the standard deviation has decreased from 0.3082 to 0.208125. The process yield is increase to 36 % items without defects. The value of sigma level has increased from 1.4 to 2.42 which means reduction in defect products, so that DPMO value has been reduced from 536804 to 185795.09 and the profit increased from ID 127.000 to ID 226.000 per 1000 kg.

4. Conclusions and recommendations for future work

The conclusions and recommendations that are drawn from this work are as follows:

- Profits of implementation DMAIC methodology are accomplished in expression of cost decrease and remove aluminium products defects.
- The values for process capability measures (C_p, C_{pk}) indicate the ability to process improves or not. If the values are less than 1.0 as for CQC (X1) this situation point out the process mean deviation for aluminium product design specification (target value).
- The extrusion process mean increased, the extrusion process dispersion decreased and the process extrusion very nearer to target value.
- Based on the results, the sigma levels values increased depending on the implemented suggested solution. Therefore, this improvement is not sufficient to reach the value of six sigma level.
- The results prove that the DMAIC methodology is effective in estimation, analysis and improvement process capability of data that are normally distributed.
- Study the process capability improvement (DMAIC methodology) by using simulation technique to test and improve the effectiveness of suggested solution before they are implemented.
- The possibility of the DMAIC methodology application in the other aluminium products and other product defects were not able to study in this work due to the limitation of research time.

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