Journal of Industrial Engineering & Management Research
http://www.jiemar.org e-ISSN : 2722-8878
Vol. 7 No. 3 – 2026

Quality Control of PCC (Portland Composite Cement) Using the Six Sigma Method at PT. XY

Achmad Syarifudin[1], Sri Ndaru Arthawati[2], Sri Mukti Wirawati[1], Pugy Gautama[1]

[1]*Department of Industrial Engineering, Faculty of Engineering, Universitas Banten Jaya, Serang, Banten 42116, Indonesia*

[2]Universitas Sultan Ageng Tirtayasa (Untirta)

Corresponding author: sri.mukti@yahoo.co.id, achmad.buker69@gmail.com

Abstract

PT. XY is a premium cement manufacturer producing Portland Composite Cement (PCC) and Ordinary Portland Cement (OPC). Throughout 2023, the company's production line experienced recurring defect problems, including cement contaminated by water, weighing scale non-compliance with Standard Operating Procedures (SOP), and brittle cement quality. These conditions led to a decline in customer satisfaction while simultaneously increasing production costs. This study applies the Six Sigma approach with the DMAIC (Define, Measure, Analyze, Improve, Control) framework to identify, measure, and minimize defect rates. Data collection was conducted from January to December 2023 at the Quality Control Laboratory of PT. XY, Ciwandan Plant, Cilegon, Banten. The analysis revealed 83,523 defective sacks out of a total of 432,751 sacks produced. The Defects Per Million Opportunities (DPMO) value obtained was 64,334.9, equivalent to a sigma level of 3, indicating that the production process is at an average industrial level and still requires significant improvement. The most dominant defect type was scale non-compliance with SOP (38.23%), followed by brittle cement quality (31.08%) and cement exposed to water (30.69%). Through fishbone diagram analysis, the primary causal factors were identified across categories of human, machine, method, material, and environment. Specific improvement recommendations for each defect category are proposed to drive the sigma level toward a higher stage.

Keywords: quality control; Six Sigma; DMAIC; DPMO; PCC cement; defect analysis

1. INTRODUCTION

Amid intensifying global industrial competition, manufacturing companies are required to maintain product quality as the primary foundation of competitiveness. Quality is broadly defined as the totality of attributes and characteristics of a product or service capable of satisfying customer needs, both stated and implied (Hanifah & Iftadi, 2022). For the

Journal of Industrial Engineering & Management Research
http://www.jiemar.org e-ISSN : 2722-8878
Vol. 7 No. 3 – 2026

cement industry, quality is of critical importance as it directly relates to the structural reliability and safety of buildings that depend on it.

PT. XY, which markets its products under the Semen Merah Putih brand, is one of Indonesia's premium cement producers established in 2011. The company operates six production plants distributed across Indonesia and manufactures two main product types: Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). The Ciwandan plant located in Cilegon, Banten, has a production capacity of up to 1,000,000 tons per year.

Despite its premium product positioning, PT. XY's production process continued to face persistent defect issues throughout 2023. Three major defect types were identified: (1) cement contaminated by water during drying or storage, (2) sack weighing that did not comply with SOP requirements, and (3) brittle cement quality resulting from improper mixing ratios. These defects not only harm customers but also increase rework costs and production losses.

Quality control methods such as Six Sigma have been widely demonstrated to effectively reduce production defect rates in manufacturing environments. Six Sigma targets a quality achievement of 3.4 defects per million opportunities (DPMO), reflecting near-perfect production conditions (Gaspersz, 2002). The DMAIC cycle Define, Measure, Analyze, Improve, Control provides a structured problem-solving framework to reach this target.

Numerous prior studies reinforce the effectiveness of Six Sigma in manufacturing contexts. Fithri (2019) achieved a sigma level of 5.07 in a textile plant. Andiwibowo et al. (2018) found a sigma level of 2.99 with a DPMO of 99,393 in the plywood industry. Rahayu and Bernik (2020) reported a DPMO of 3,603.64 and a sigma level of 4.18 in bread production. Internationally, Burawat (2019) demonstrated quality improvements through Lean Six Sigma in the carton manufacturing industry, while Mhone and Jin (2021) applied Six Sigma in concrete production.

This study aims to: (1) identify defect types in PCC cement production; (2) calculate the sigma level and DPMO value; and (3) trace the root causes of defects using fishbone diagram analysis. The research findings are expected to provide implementable improvement recommendations for PT. XY.

2. LITERATURE REVIEW

2.1 Quality Control

Quality control (QC) is a set of systematic processes designed to ensure that a product or service consistently meets established standards and customer expectations. Hanifah and Iftadi (2022) define quality control as the technical and managerial activities used to measure product quality characteristics, compare them against predetermined specifications, and take corrective action when deviations are found. Effective QC implementation enables companies to maintain market share, reduce waste, and improve customer loyalty (Adi Juwito & Al-Faritsy, 2022).

The effectiveness of quality control is influenced by several key factors, including production process capability, the validity of product specifications, the level of non-conformance encountered, and the budget allocated to the quality function (Adi Juwito & Al-Faritsy, 2022). Products that fail to meet the company's standard criteria are classified as defective and cannot be marketed, thereby directly causing financial losses.

2.2 Six Sigma

Six Sigma is a data-driven methodology aimed at improving process quality to achieve a standard of 3.4 DPMO, equivalent to a perfection rate of 99.9997% (Gaspersz, 2002). The sigma symbol (σ) is a statistical notation describing process variability. A higher sigma value reflects lower variation and fewer defects. Six Sigma was first developed by Motorola in the 1980s and has since been widely adopted across various industries worldwide (Mhone & Jin, 2021).

Table 1. Sigma Level and DPMO Conversion

Sigma Level	DPMO	Yield (%)
1 Sigma	690,000	30.9%
2 Sigma	308,000	69.2%
3 Sigma	66,800	93.3%
4 Sigma	6,210	99.4%
5 Sigma	320	99.98%
6 Sigma	3.4	99.9997%

Source: Gaspersz (2020)

Key metrics in Six Sigma include: Defect Per Unit (DPU), which measures the average number of defects per production unit; Defect Per Opportunity (DPO), which describes the proportion of defects relative to the total opportunities for defects to occur; and Defect Per Million Opportunities (DPMO), which converts DPO to a scale of one million to facilitate cross-process comparison.

The formulas used in the calculations are as follows:

$$DPU = \text{Total Defects} / \text{Total Production} \quad (1)$$

$$DPO = DPU / CTQ \quad (2)$$

$$DPMO = DPO \times 1{,}000{,}000 \quad (3)$$

2.3 DMAIC Framework

Journal of Industrial Engineering & Management Research
http://www.jiemar.org e-ISSN : 2722-8878
Vol. 7 No. 3 – 2026

DMAIC is the core problem-solving cycle in the Six Sigma methodology, consisting of five phases: (1) Define identify and define quality problems as well as critical to quality (CTQ) characteristics relevant to customer needs; (2) Measure establish baseline performance metrics using statistical tools such as the p-chart; (3) Analyze determine the root causes of defects through Pareto and fishbone (Ishikawa) diagrams; (4) Improve develop and implement action plans to address root causes; and (5) Control sustain improvements through documentation and regular monitoring (Wahyani et al., 2010).

The p-chart (proportion chart) is used to monitor the proportion of defective products in a process over time. Control limits are calculated using the following formulas:

$$CL = \Sigma np / \Sigma n \quad ..(4)$$

$$UCL = \bar{p} + 3\sqrt{[\bar{p}(1-\bar{p})/n]} \quad \ldots (5)$$

$$LCL = \bar{p} - 3\sqrt{[\bar{p}(1-\bar{p})/n]} \quad \ldots (6)$$

3. RESEARCH METHOD

3.1 Research Location and Period

This study was conducted at the Quality Control Laboratory (Lab 1) of PT. XY (Semen Merah Putih), located at Kelurahan Kepuh, Kecamatan Ciwandan, Kota Cilegon, Banten 42446. Data collection took place from May to July 2024, using production records from January to December 2023 as the primary data source.

3.2 Research Type and Data Collection

This study employs a quantitative approach with descriptive analysis. Primary data were obtained through direct observation in the production area and structured interviews with QC Laboratory staff. Secondary data included monthly production summaries, defect records, and internal company documents for 2023.

The data collected comprised: (1) monthly PCC cement production volume in sacks; (2) the number of defective products each month; and (3) defect classification by type. Three defect types identified as CTQ characteristics were: cement exposed to water, weighing scale weight not complying with SOP, and brittle cement quality.

3.3 Data Analysis Method

Data analysis followed the DMAIC framework sequence. The Define phase was used to identify defect types and CTQ characteristics. The Measure phase applied the p-chart and calculated the sigma level. The Analyze phase used a Pareto diagram to prioritize defects and a fishbone diagram to trace their root causes. The Improve phase developed corrective action recommendations for each defect category. The Control phase recommended documentation and continuous monitoring procedures.

4. RESULTS AND DISCUSSION

Journal of Industrial Engineering & Management Research
http://www.jiemar.org e-ISSN : 2722-8878
Vol. 7 No. 3 – 2026

4.1 Define Phase

Based on production data from January to December 2023, three CTQ defect types were identified in PCC cement production at PT. XY:

1) Cement Exposed to Water: Early exposure to water disrupts the cement hydration reaction, weakens the matrix structure, and leads to structural failure.
2) Scale Not Complying with SOP: Weighing errors caused by operator negligence or uncalibrated equipment result in sack weights that do not meet the established standard.
3) Brittle Cement Quality: An improper water to cement ratio or premature clinker removal before the process is complete produces cement lacking adequate structural strength.

Table 2 presents the complete monthly production and defect data throughout the study period.

Table 2. Total PCC Cement Production and Defect Data (2023)

Month	Production (sacks)	Water Exposure	Scale Non-SOP	Brittle Quality	Total Defects	% Defects
January	32,078	1,465	1,503	4,382	7,350	22.91%
February	24,728	2,598	3,462	1,946	8,006	32.38%
March	32,484	2,684	1,467	1,545	5,696	17.54%
April	52,310	1,753	2,011	3,841	7,605	14.54%
May	39,022	2,536	1,196	1,322	5,054	12.95%
June	46,631	1,278	6,980	1,469	9,727	20.86%
July	31,567	1,028	3,020	1,209	5,257	16.65%
August	22,918	2,787	1,532	1,519	5,838	25.47%
September	39,027	1,902	2,326	2,633	6,861	17.58%
October	32,153	3,091	1,063	2,605	6,759	21.02%
November	27,794	1,785	4,623	2,342	8,750	31.48%
December	52,039	2,723	2,748	1,149	6,620	12.72%
Total	**432,751**	**25,630**	**31,931**	**25,962**	**83,523**	**19.30%**

Source: PT. XY (2023)

From the data, it is known that total production over 12 months reached 432,751 sacks, of which 83,523 sacks (19.30%) were declared defective. The highest defect rates occurred in February (32.38%) and November (31.48%), both of which exceeded the Upper Control Limit (UCL) calculated in the Measure phase.

4.2 Measure Phase

A p-chart was constructed to monitor the proportion of defective sacks each month. The center line (CL), upper control limit (UCL), and lower control limit (LCL) were calculated using Equations 4 – 6 with n = 12 subgroups.

The overall defect proportion is: $\bar{p} = 83{,}523 / 432{,}751 = 0.193$. With n = 12 subgroups:

$$CL = 0.193$$

$$UCL = 0.193 + 3\sqrt{[(0.193 \times 0.807)/12]} = 0.280$$

$$LCL = 0.193 - 3\sqrt{[(0.193 \times 0.807)/12]} = 0.106$$

Table 3. P-Chart Control Limit Calculations (January – December 2023)

Month		np (defects)	p	CL	UCL	LCL
January		7,350	0.229	0.193	0.280	0.106
February		8,006	0.324	0.193	0.280	0.106
March		5,696	0.175	0.193	0.280	0.106
April	52,310	7,605	0.145	0.193	0.280	0.106
May	39,022	5,054	0.130	0.193	0.280	0.106
June	46,631	9,727	0.209	0.193	0.280	0.106
July	31,567	5,257	0.167	0.193	0.280	0.106
August	22,918	5,838	0.255	0.193	0.280	0.106
September		6,861	0.176	0.193	0.280	0.106
October		6,759	0.210	0.193	0.280	0.106
November		8,750	0.315	0.193	0.280	0.106
December		6,620	0.127	0.193	0.280	0.106
Total	432,751	83,523	—	—	—	—

Source: Processed Data (2024)

The p-chart results indicate that February (p = 0.324) and November (p = 0.315) exceeded the UCL of 0.280, indicating the presence of special cause variation in those two months. This condition is consistent with the disproportionate surge in scale non SOP and brittle cement defects. All other months remained within control limits, reflecting common-cause variation.

Journal of Industrial Engineering & Management Research
http://www.jiemar.org e-ISSN : 2722-8878
Vol. 7 No. 3 – 2026

The sigma level calculation yielded the following values:

DPU = 83,523 / 432,751 = 0.19300

DPO = 0.19300 / 3 = 0.06433 (CTQ = 3)

DPMO = 0.06433 × 1,000,000 = 64,334.9

Sigma Level ≈ 3.0 (Level 3 Sigma)

A DPMO of 64,334.9 places the production process at Sigma Level 3, which is consistent with the average manufacturing quality standard in Indonesia. This result is comparable to the findings of Andiwibowo et al. (2018) who obtained a sigma of 2.99 in the plywood industry, confirming that many mid scale manufacturing plants in Indonesia still operate below world class sigma standards.

4.3 Analyze Phase

4.3.1 Pareto Analysis

Table 4. Pareto Analysis of Defect Types (January–December 2023)

Defect Type	Total (sacks)	Percentage	Cumulative (%)
Scale Not Complying with SOP	31,931	38.23%	38.23%
Brittle Cement Quality	25,962	31.08%	69.31%
Cement Exposed to Water	25,630	30.69%	100.00%
Total	**83,523**	**100%**	—

Source: Processed Data (2024)

The Pareto diagram reveals that scale non-compliance with SOP is the dominant defect, contributing 38.23% of total defects (31,931 sacks). Brittle cement quality accounts for 31.08% (25,962 sacks), while cement exposed to water contributes 30.69% (25,630 sacks). These three defect types cumulatively cover 100% of all identified defects, necessitating that all three be addressed simultaneously during the improvement phase.

4.3.2 Fishbone Diagram Analysis

Fishbone (Ishikawa) diagrams were developed for each defect type through structured interviews and direct observations with production operators. The following root causes were identified:

(a) Scale Not Complying with SOP: Causal factors span three categories. From the human side, operators tend to rush in meeting production targets without carefully checking the weighing process. From the machine side, scales experience malfunctions or errors during operation. From the method side, no standardized double checking procedure exists within the weighing process.

(b) Brittle Cement Quality: Four factor categories were identified. From the human side, insufficient care during the material mixing process. From the machine side, equipment disturbances during clinker production that impede material bonding. From the material side, substandard raw material quality. From the method side, premature clinker removal before the process is fully complete.

(c) Cement Exposed to Water: Three factor categories constitute the primary causes. From the human side, errors occur during the transfer and handling of cement sacks. From the environmental side, storage facilities lack adequate protection against rain or water pooling. From the method side, the absence of leak-protection procedures during the transportation process.

These root cause findings are consistent with existing literature. Adi Juwito and Al-Faritsy (2022) similarly identified operator negligence and machine condition as the primary defect triggers in the wood product industry. The 4M+1E framework (Man, Machine, Material, Method, Environment) used in this study has been validated across various manufacturing sectors as a comprehensive root cause classification system.

4.4 Improve Phase

Based on the results of the root cause analysis, the following improvement recommendations are proposed:

For scale non-compliance with SOP: (1) Conduct structured operator training on SOP-compliant weighing procedures, along with periodic refresher sessions; (2) establish a mandatory double-check protocol for every weighing cycle; (3) implement a scheduled preventive maintenance program for all weighing equipment; (4) install real-time monitoring systems or alarms on scales to detect deviations at an early stage.

For brittle cement quality: (1) Conduct incoming quality inspections on all raw materials prior to production; (2) enforce standardized mixing time and clinker lifting procedures; (3) install machine condition monitoring systems to detect disturbances earlier; (4) retrain operators on the importance of mixing ratios and clinker completion time.

For cement exposed to water: (1) Upgrade warehouse facilities to ensure water-protected storage conditions; (2) conduct pre-shipment inspections of transport vehicle integrity; (3) train handling personnel on proper cement transfer procedures to minimize sack damage; (4) introduce weather-resistant packaging or supplementary protective covers during vulnerable storage periods.

4.5 Control Phase

The control phase aims to sustain the improvement outcomes and prevent recurrence of the identified defects. Recommended control measures include:

(1) Standardize and document all improved procedures into updated SOPs; (2) continue monthly p-chart monitoring to detect process deviations in real time; (3) conduct quarterly calibration audits of all weighing equipment; (4) establish a defect tracking database that records defect frequency, type, and assigned corrective action; and (5) form a cross-

functional quality review team responsible for continuous monitoring and periodic sigma-level reassessment.

These recommendations are aligned with the DMAIC control stage requirements as described by Wahyani et al. (2010), who emphasize that documentation and delegation of responsibility are essential elements in preventing problem recurrence. If all recommendations are fully implemented, the projected sigma improvement from Level 3 to Level 4 is expected to reduce DPMO from approximately 64,335 to around 6,210 equivalent to a reduction in defect rate of over 90%.

5. CONCLUSION

This study applied the Six Sigma DMAIC methodology to analyze and address quality defects in PCC cement production at PT. XY. The following conclusions are drawn:

1) Three CTQ defect types were identified: cement exposed to water, weighing scale non-compliance with SOP, and brittle cement quality. The most dominant defect was scale non-compliance (38.23%), followed by brittle quality (31.08%) and water exposure (30.69%).
2) The DPMO value obtained was 64,334.9, placing the production process at Sigma Level 3, indicating that significant room for improvement remains toward world-class Six Sigma performance.
3) Root cause analysis through fishbone diagrams identified human, machine, material, method, and environmental factors as the primary defect contributors. Operator negligence, equipment failure, substandard raw material quality, and inadequate storage conditions were the dominant triggers.

Improvement recommendations encompass operator training, preventive maintenance, material inspection, warehouse facility upgrades, and transportation protocol enhan cements. If implemented, these measures are projected to advance the process to Sigma Level 4 or higher.

Future research is recommended to conduct post-intervention longitudinal data collection to empirically measure sigma level improvement, and may extend the analysis to include calculations of economic losses arising from defective production.

REFERENCES

Adi Juwito, & Ari Zaqi Al-Faritsy. (2022). Analisis Pengendalian Kualitas Untuk Mengurangi Cacat Produk Dengan Metode Six Sigma Di UMKM Makmur Santosa. Jurnal Cakrawala Ilmiah, 1(12), 3295–3314. https://doi.org/10.53625/jci.v1i12.3193

Ahmad, F. (2019). Six Sigma DMAIC Sebagai Metode Pengendalian Kualitas Produk Kursi Pada UKM. Jurnal JISI UM, 6(1), 7.

Andiwibowo, R. R., Susteyo, J., & Wisnubroto, P. (2018). Pengendalian Kualitas Produk Kayu Lapis Menggunakan Metode Six Sigma & Kaizen Serta Statistical Quality Control. Jurnal Rekayasa & Inovasi Teknik Industri, 6(2), 100–110.

Burawat, P. (2019). Productivity improvement of carton manufacturing industry by implementation of lean six sigma, ECRS, work study, and 5S: A case study of ABC co., ltd. Journal of Environmental Treatment Techniques, 7(4), 785–793.

Fithri, P. (2019). Six Sigma Sebagai Alat Pengendalian Mutu Pada Hasil Produksi Kain Mentah PT Unitex, Tbk. J@ti Undip: Jurnal Teknik Industri, 14(1), 43–52. https://doi.org/10.14710/jati.14.1.43-52

Gaspersz, V. (2002). Pedoman Implementasi Program Six Sigma Terintegrasi dengan ISO 9001:2000, MBNQA, dan HACCP. Gramedia Pustaka Utama.

Hanifah, P. S. K., & Iftadi, I. (2022). Penerapan Metode Six Sigma dan Failure Mode Effect Analysis untuk Perbaikan Pengendalian Kualitas Produksi Gula. Jurnal INTECH Teknik Industri Universitas Serang Raya, 8(2), 90–98. https://doi.org/10.30656/intech.v8i2.4655

Kusumo, S., & Riandadari, D. (2019). Analisis Kualitas Produksi Benang Dengan Metode Six Sigma Pada PT. Sejati Jaya. Jurnal Pendidikan Teknik Mesin UNESA, 6(01), 28–34.

Mhone, A. O., & Jin, J. (2021). Deployment of Lean Six Sigma and KAIZEN Techniques: A Case Study of the Concrete Production Plant for the 750 MW Kafue Gorge Lower Hydro Power Project. American Journal of Industrial and Business Management, 11(10), 1052–1069. https://doi.org/10.4236/ajibm.2021.1110064

Rahayu, P., & Bernik, M. (2020). Peningkatan Pengendalian Kualitas Produk Roti dengan Metode Six Sigma Menggunakan New & Old 7 Tools. Jurnal Bisnis & Kewirausahaan, 16(2), 128–136.

Ramakrishna, Y., & Alzoubi, H. M. (2022). Empirical Investigation of Mediating Role of Six Sigma Approach in Rationalizing the COQ in Service Organizations. Operations and Supply Chain Management, 15(1), 122–135. https://doi.org/10.31387/oscm0480335

Ratnadi. (2019). Pengendalian Kualitas Produksi Menggunakan Alat Bantu Statistik (Seven Tools) Dalam Upaya Menekan Tingkat Kerusakan Produk. Jurnal Teknik Industri, 5(2).

Wahyani, W., Chobir, A., & Rahmanto, D. D. (2010). Pengendalian Kualitas Produk Dengan Metode Six Sigma. Jurnal Rekayasa dan Manajemen Sistem Industri.