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EVALUATING QUALITY AS A KEY PERFORMANCE PARAMETER IN CERAMIC TILES MANUFACTURING

Prof. Harshad D. Santoki
Dr. Ghanshyam D. Acharya
Dr. Shailee G. Acharya[3]

Abstract:
Ceramic tiles manufacturing is a fast-growing industry in India, which is one of the fastest developing country in the world. Due to competitive market environment, there is always a pressure on manufacturer to improve performance. Considering the process characteristics of ceramic tiles manufacturing, the improvement of quality is becoming more important. This research paper describes work done to enhance product quality by designing and implementing a systematic framework in a ceramic tiles manufacturing SME unit. Quality has been evaluated by taking into account three main quality characteristics of tiles: dimensional accuracy, appearance and strength. Different quality improvement tools and techniques have been applied with a main focus on statistical process control (SPC) tools and methods. Statistical analysis of the process was carried out using Minitab software. The results indicate that the objectives are met, as shown by a noticeable increase in quality as a key performance indicator.
Keywords: Quality Improvement, Quality Management, Statistical Process Control, Performance Parameter, Ceramic Tile Manufacturing.

1 INRODUCTION

Quality can be defined as fitness at the most economical level for use or function. Quality management is concerned with reducing uncertainty in processes and goods. It can be ensured at different stages of the process by applying appropriate procedures and controls (T.R. Vijayaram et al.,2006). For quality assurance, there are several tools and techniques available. Statistical Process Control (SPC) is useful in achieving stability and strengthening the performance of the manufacturing process. Emphasizing the attainment of satisfactory product and service quality, multi-stage surveillance and fault diagnosis has become a requirement. Methods of Statistical Process Control (SPC) have been generally accepted as efficient process monitoring and diagnosis approaches (Tsung, F., Li, Y., & Jin, M., 2008). The quality enhancement system framework represents company-wide activities to improve the quality level of products and works by integrating various instruments and techniques for improving quality. This aids in making the process fool proof and the process variance can be recognized and minimized with the use of statistical process control. The improvement in quality requires a course of sequence that starts with the symptom and passes to the solution through the identification of the causes. The reduction in process variability contributes to a decrease in rejections and waste and thereby decreases the cost of output. Quality management (QM) has become an all-encompassing management philosophy that has pervaded most countries and industries (Sousa, R., 2003). Systematic quality management can be used as one of the strategic weapons for maintaining competitive advantage in manufacturing companies (Phan, A. C., Abdallah, A. B., & Matsui, Y., 2011).

2 LITERATURE REVIEW

The Improvement of quality requires reducing the variability that is undesirable. As variability can be represented only in statistical terms, statistical methods play a central role in improving quality. To monitor and improve manufacturing processes and service activities, statistical process control (SPC) methods are widely used. (Woodall, W. H., 2000). In order to increase the efficiency of a process, statistical process control (SPC) uses statistical techniques. (E.M. Smeti et al.). It is a widely accepted production phenomenon that the implementation of statistical process control (SPC) within production environments can increase quality, productivity, and costs (Rungtusanatham, M., 2001). There is no doubt that understanding the structure of the process and quantifying the performance of the process is important for successful quality improvement programs. In the course of some 20 years, process capacity analysis has become an essential and well-defined instrument for continuous improvement of quality and productivity in statistical process control (SPC) applications (Wu, C. W., Pearn, W. L., & Kotz, S, 2009). In order to produce the required production rates of high quality goods, manufacturing firms are continually facing the challenge of operating their production processes and systems while optimizing the use of resources (Colledani, M., Tolio, T., Fischer, A., Iung, B., Lanza, G., Schmitt, R., & Váncza, J. 2014). Dr.-Ing. Kerstin Schwab (2013) proposed a holistic methodological model for applying QM-Methods and is based on the Deming Circle. Gasper Skulj et al. (2013) proposed service-driven approach to SPC, in which SPC is outsourced through the use of modern information and communication technology, such as web services. Control charts with statistical tools and transparent online graphical representation of outcomes in real time are the focus of the SPC service.

E.M. Smeti et al. (2007) emphasized on the use of statistical tools to enhance quality management. Ali Mostafaeipour et al. (2012) have addressed an industrial case that how the application of SPC helps to improve quality control. Dorde Vukeli et al. (2008) presented statistical quality management approaches for the assessment of process stability and capability. Dhafr N. et al. (2006) has developed a quality management framework for manufacturing organizations that provides a model for recognizing different sources of product quality defects. The integration of improvement tools within a single system has been shown to be an effective way of making significant improvements in manufacturing performance. Amasaka, K. (2003) introduced the "science SQC" as a a systematic and organizational SQC implementation technique for the manufacturing industry and its efficacy addressed on the basis of verification studies carried out by Toyota Motor Corporation. Manabu Kanoa et al. (2008) surveyed data based process monitoring and control techniques and presented data-driven quality improvement. DDQI builds a mathematical model based on operational data, analyzes the cause of inferior output and low yield, selects manipulated variables and optimizes the operating conditions that can achieve the desired quality. Gwang-Rim Yi et al. (2002) provided the functional framework for a quality-oriented shop floor control system (QSFCS) for large-scale manufacturing processes. The framework has been applied to the manufacturing process of the shadow mask, which consists of a few hundred process parameters and about 40 quality features.

After reviewing the published literature and arranging brainstorming session with the top management of company, it was ascertained that the quality management framework for the manufacture of ceramic tiles could be designed by combining all QM methods and techniques with a main emphasis on SPC.

3 CASE PROBLEM DESCRIPTION

3.1 About Case Company

A case study has been undertaken at a SME unit manufacturing ceramic wall tiles located in Morbi, India, which is one of the largest ceramics manufacturing clusters in the world. Company operates in competitive domestic and international market environment. Due to increasing market competition and dynamic manufacturing situation, the company is facing challenges to improve its manufacturing system performance. Quality improvement program would have major impact in achieving overall improvement in manufacturing system. The ceramic tile manufacturing is a flow style process consisting of different stages of processing. Material preparation, shaping (pressing), pre-glaze firing (drying), glaze application, tile printing, post glaze firing, final inspection and sorting, packaging and storage are the main stages in the production process of ceramic wall tiles. Company is manufacturing ceramic wall tiles.

3.2 Quality Grading of Ceramic Tiles

Ceramic wall tiles produced in the factory are graded after final inspection and sorted into three grades with different sales price values depending on the quality of the tiles (Table 1). It is obvious that the company has a loss of revenue in the inferior grades (second and third grade) of tiles produced because they have to be sold at reduced rates. Improving quality is therefore a major concern to be addressed in order to boost manufacturing performance.

Table 1.Quality grades-wise performance of ceramic tiles output at initial phase

Sr. No.	Grade of Tiles	Level of Quality (Type of Defects Observed)	Percentage of Output	Value of a Tile (% of Unit Selling Price)
1	First	High (No defect)	95	100
2	Second	Moderate (Minor surface defect)	2	60
4	Third	Low (Major defects)	3	25

3.3 Criteria for Quality Grades Sorting

Sorting and quality grading of tiles produced is done as per criteria that is mainly based on company policy and also considering prevailing national and international quality standards of ceramic tiles (Table 2).

Table 2 Quality Grades Sorting Criteria

Quality Characteristics	Quality Grade-wise Sorting Criteria		
	First Grade	Second Grade	Third Grade
Length & (Width (mm	0.2 +	0.3 +	0.5 +
Thickness ((mm	0.2 +	0.3 +	0.5 +
Curvature ((mm	(to (+ 0.5 (0.1 +)	to + 0.8 0	0 > / 0.8 <
Surface Quality	free from % 95 defect	Minor defects allowed	All surface defects allowed
Glaze Dirt	Not allowed	Small dirt allowed	Allowed
Pin Hole	Not allowed	Minor pin holes allowed	Allowed
Corner Chipping	Not allowed	Minor allowed	Allowed
Misprint	Not allowed	Minor misprint allowed	Allowed
Crack	Not allowed	Not allowed	Up to 2 inches
Blister	Not allowed	Not allowed	Allowed
Black Dust	Not allowed	Not allowed	Allowed
Shade Variation	Not allowed	Allowed	Allowed
Curvature beyond limits	Not allowed	Not allowed	Allowed
Crazing	Not allowed	Not allowed	Allowed

Justification for sorting tiles in to different quality grades:

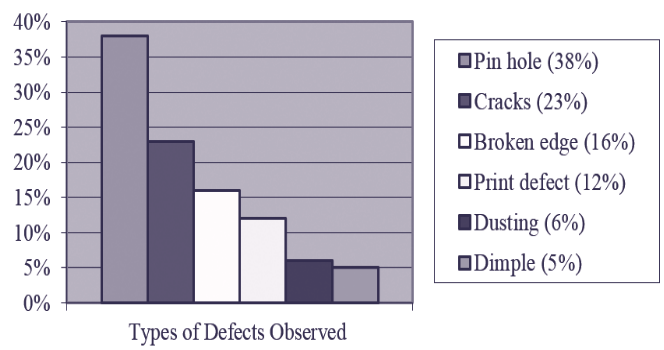
- It is a common practice in the manufacturing industry of ceramic wall tiles to sort the tiles produced in various grades according to their level of quality.
- It is to the advantage of the consumers, as they have to pay just for the amount of quality of the product they are receiving.

- On the other hand, by selling them at a cheaper price, the company can also recover any portion of the production cost on lower quality tiles that otherwise have to be scraped out and can add additional costs for their disposal.

3.4 Type of Defects Observed in Ceramic Tiles Produced

The type of defects found in the company's manufactured ceramic wall tiles are shown in the following chart with details of their percentage of occurrence (Fig.1). The main defects found affecting the quality of tiles are pin-holes and cracks. In order to determine the causes of a particular defect, it is important to carry out an investigation of the incidence of each defect, so that necessary corrective steps can be taken to avoid it. Detailed analysis was carried out for the same which is outlined in the next section of this paper.

Figure 1 Types & Extent of Defects Observed in Tiles Production



3.5 Objectives of the work

The following are the objectives of this work.

- To design and implement quality improvement system framework by integrating various tools and techniques.
- To enhance process capability using SPC tools.
- To improve quality level of the product.

4 METHODOLOGY

A systematic methodology was adopted to address the issue and achieve the desired objectives that include the following actions.

1.1 Key Quality Characteristics Addressed

Below mentioned are important quality characteristics of ceramic wall tiles, which have been taken into account while designing the proposed quality improvement system framework.

- Dimensional accuracy (Length & Width and thickness)
- Appearance (Finish, Glaze & Printing Quality)
- Strength (Modulus of rupture)

1.2 Analysis for the causes of defects

For analyzing the causes of defects, brainstorming sessions were carried out by staff of different sections of the company including materials, QC, press, kiln, glaze and printing sections. Causes for each defect were indentified and necessary actions were taken to prevent their occurrences. Table 3 shows outcome of the analysis carried out.

Table 3 Analysis for the causes of defects and remedial actions taken

Type of Defect	Causes of the defect	Remedial actions taken to prevent the occurrence of defect
Pin hole (38%)	➢ Variation in the composition of body materials or in the properties of raw materials ➢ Frit content impurities ➢ Low glaze material residue ➢ Excessive porosity of biscuit tiles ➢ Improper Gasification	➢ Rigorous monitoring of incoming raw material quality ➢ Control of the firing process and temperature in various kiln zones
Cracks (23%)	➢ Unbalanced punch / die or press issues such as jerking, low pressure, Clay filling not properly ➢ Low Green Tile Strength ➢ Low Moisture content in the mixture of clay ➢ Low material plasticity ➢ Low green tile bulk density	➢ Preventive maintenance of the press section has started ➢ Proper regulation of Press Parameters ➢ Controlling consistency of clay mixture granulometry at 80% and clay moisture at 5-5.5%
Broken Edge (16%)	➢ Low tile strength ➢ Tile touching inside the kiln ➢ Problem in the handling of tiles	➢ Worker instructed for careful handling of tiles ➢ Frequent and careful inspection has started
Print Defect (12%)	➢ Head choked up in printing machine ➢ Poor quality of ink ➢ Improper printing machine setting	➢ Frequent checking of head ➢ Assured good quality ink ➢ Ensuring correct settings in printing machines
Dusting (6%)	➢ Blower of the kiln not running well ➢ The kiln burner was not cleaned properly ➢ Kiln roof & pipe not adequately cleaned	➢ Regular & frequent kiln inspection and maintenance has started.
Dimple (5%)	➢ High level of residue in glaze material ➢ Content of oil in glaze material ➢ Falling particles of dust on green tiles	➢ Strict quality monitoring of the glaze material ➢ Prevented the accumulation of dust on green tiles by increasing level of cleanliness

Tests for checking rupture strength of tiles and crazing defect on tiles surface have been introduced as a part of quality improvement system framework.

1.3 Capability Analysis for the Dimensional Accuracy of Tiles

As an imperative for a company's survival, continuous quality improvement includes the development of a process measurement system. Measurement data must be arranged, processed and evaluated using suitable methods and techniques in order to assess the possibilities for enhancing process effectiveness and performance (Vukelic, D., Hodolic, J., Vrecic, T., & Kogej, P., 2008). For analyzing capability of the process for dimensional accuracy of the tiles manufactured in the company, data were collected by measuring length, width and thickness of samples of tiles; for 30 subgroups with subgroup size of 5. Hence total 150 samples of tiles were collected randomly. Process capability analysis was carried out by using capability sixpack tool of minitab 14 software for all three dimensions of ceramic tiles manufactured in the company for the periods before and after implementation of quality improvement program (Fig.2 to fig.7).

Figure 2 Capability sixpack analysis for tiles length (Before improvement)

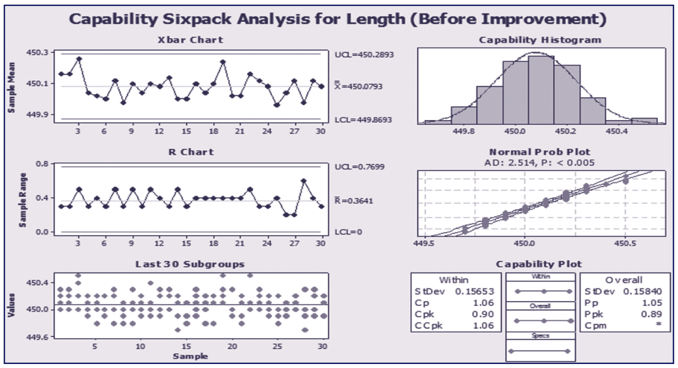


Figure 3 Capability sixpack analysis for tiles length (After improvement)

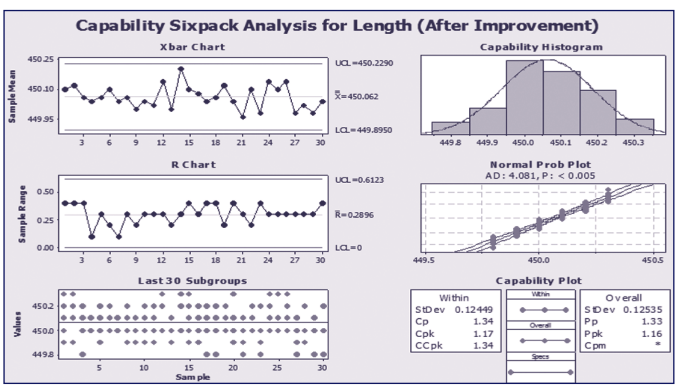


Figure 4 Capability sixpack analysis for tiles width (Before improvement)

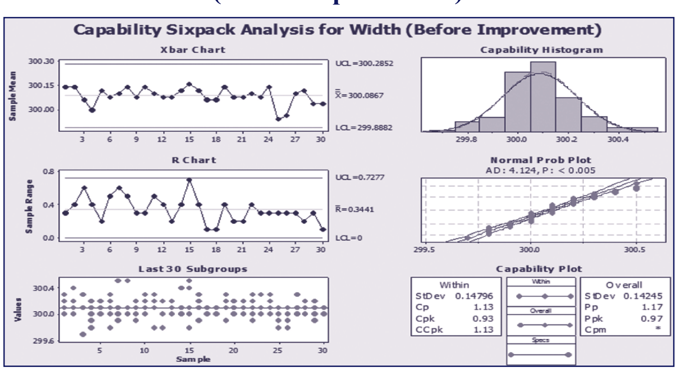


Figure 5 Capability sixpack analysis for tiles width (After improvement)

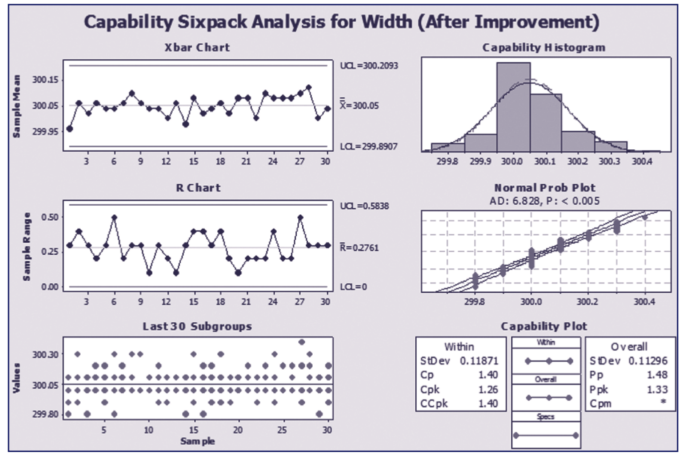


Figure 6 Capability sixpack analysis for tiles thickness (Before improvement)

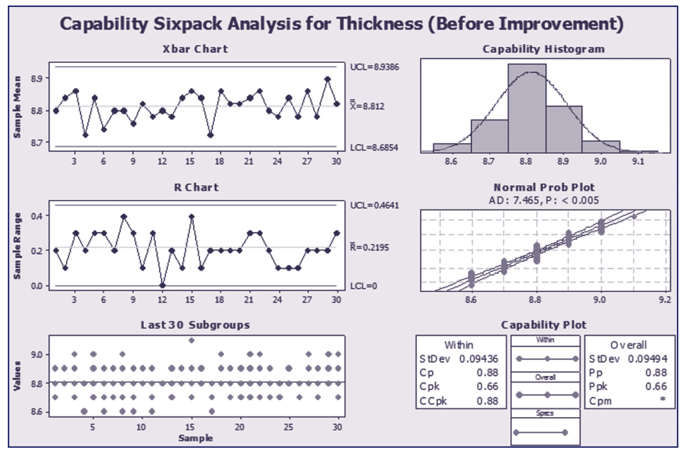
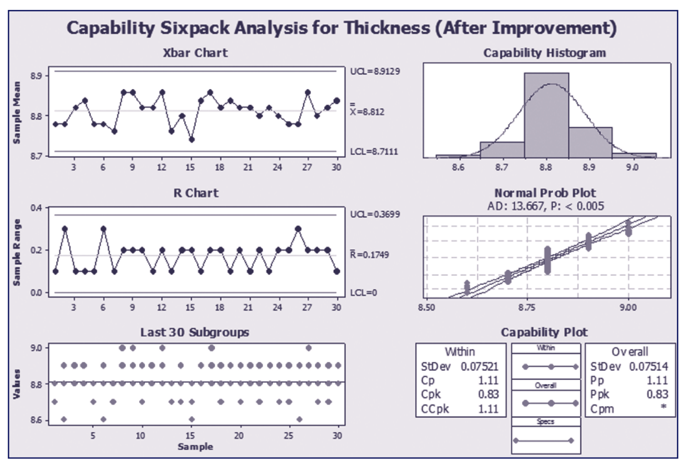


Figure 7 Capability sixpack analysis for tiles thickness (After improvement)



From the above charts (Fig. 2 to 7,) it can be noted that capability of process for dimensional accuracy has increased in the period after implementation of quality improvement program. In the case of thickness of tile during period before implementation of quality improvement program; the process capability was less than 1 showing variability in the process. Reason for this was investigated and it was due to problems in the press machine and was corrected by necessary repair and setting in the press. Then related capability value Cp has increased to 1.11 during next period of analysis.

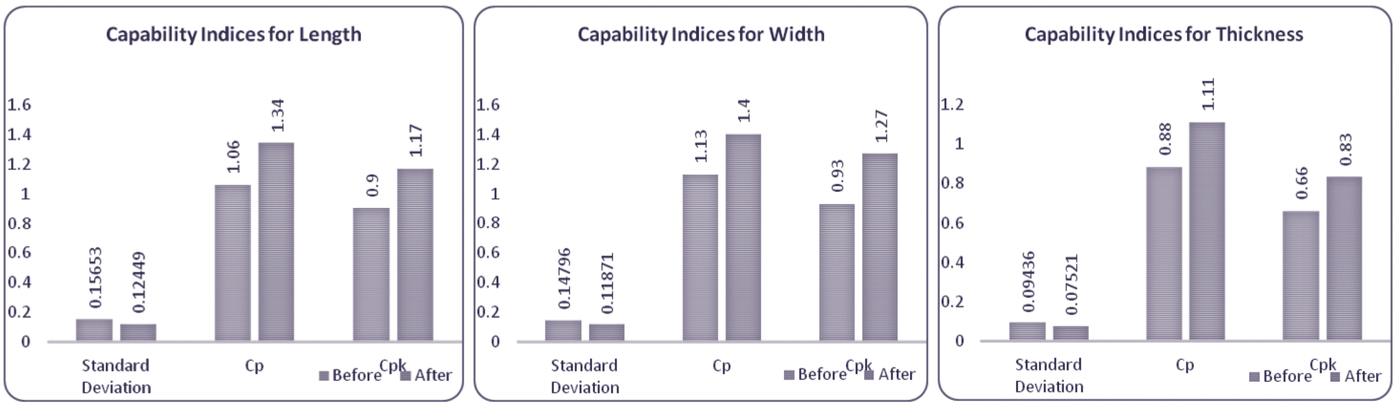
5 RESULT AND DISCUSSION

The statistical analysis of the dimensional data was carried out by using Minitab 14 software. Table 4 shows comparison of summary of the test results of statistical analysis for different sizes of ceramic tiles for the periods before and after implementation of quality improvement program.

Table 4 Comparison of the Results of the Statistical Analysis of Dimensional Data

Parameter	Size of Tiles (In mm)	Sample (N)	Standard Deviation		Process Capability Indices			
			Before	After	Cp		Cpk	
					Before	After	Before	After
Length	450	150	0.15653	0.12449	1.06	1.34	0.9	1.17
Width	300	150	0.14796	0.11871	1.13	1.4	0.93	1.27
Thickness	8.8	150	0.09436	0.07521	0.88	1.11	0.66	0.83

Figure 8 Comparison of Capability Indices for Tiles Dimensions



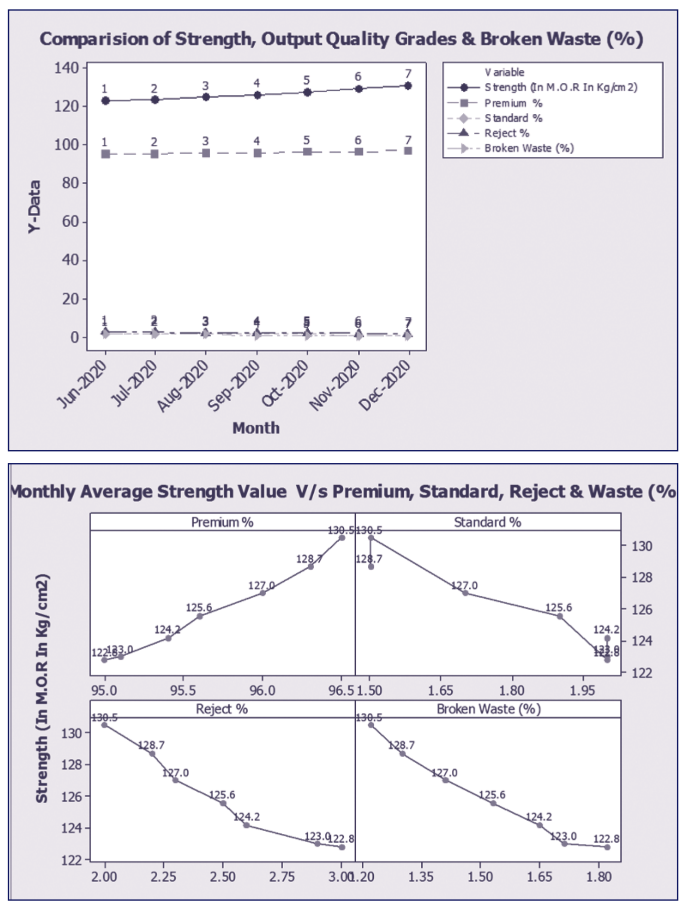
From the above comparison it can be noted that the values of process capability indices Cp and Cpk for different sizes of tiles has increased considerably and reached near to higher than 1. It means variability in the process has decreased and process has become enough capable to produce dimensionally accurate tiles that meets the specification limit. This improvement in process capability also reflects as a reduction observed in reject grade of tiles.

Table 5 Comparison of Strength, Output Quality Grade And Broken Waste Percentage

	Month	Avg. Strength M.O.R (Kg/ (cm2	(%) Output Quality Grade			Broken Waste (%)
			First	Second	Third	
Before	Jun-2020	122.8	95	2	3	1.82
After	Jul-2020	123	95.1	2	2.9	1.71
	Aug-2020	124.2	95.4	2	2.6	1.65
	Sep-2020	125.6	95.6	1.9	2.5	1.53
	Oct-2020	127	96.0	1.7	2.3	1.41
	Nov-2020	128.7	96.3	1.5	2.2	1.3
	Dec-2020	130.5	96.5	1.5	2	1.22

Month wise comparison between the values of important quality characteristics clearly indicates improvement in quality of tiles produced (Table 5).

Figure 9 Comparison charts: strength value, quality grades (%) and broken waste (%)



By comparison of monthly average values of strength, output quality grade and broken tiles percentage results data, a logical relation can be drawn between analysis, test and improvements (Fig. 9). It is evident from the above charts that, following the implementation of the quality improvement system in the company, including the introduction of the strength and craze test and the precautionary/remedial action taken to minimize defects, a month-wise increase in the average strength value (MOR) of the tiles produced was reported. The average strength has been taken as the representative strength of a ceramic tiles lot. Improved quality level of the tiles produced can also be noted with increased percentage of 'First' grade of tiles and reduced percentage of 'Second' and 'Third' grades. With month wise increase in average strength value of tiles, reduction in broken tiles waste can be noted which is also desirable. A logical connection between analysis, testing and improvements can therefore be seen.

6 CONCLUSION

Following observations in various quality parameters are noted after implementation of framework.

- The values of the indices of process capability Cp and Cpk have increased and have settled higher than 1; indicating improved process capability.
- The rate of manufactured first grade tiles rose from 95 percent to 96.5 percent, reflecting a major increase in the quality of produced tiles.
- The inferior grade rate of generated tiles decreased from 3 percent to 2 percent for the third grade and from 2 percent to 1.5 percent for the second grade.
- The rate of broken tile waste from total tile production also decreased from 1.82 per cent to 1.22 per cent.
- The tests put in place to check the strength (M.O.R.) and crazing surface have helped to ensure important quality attributes that reflect the increased average value of MOR at 130.5 Kg/cm2.
- The quality improvement program has increased the quality awareness of the company staff, which has added a non-monetary benefit.

Thus, from the above facts and figures, an overall inference can be drawn that the objectives have been successfully achieved by a systematically designed and implemented quality improvement program and quality has been proved to be a key parameter contributing in improving performance of the ceramic tile production system.

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AUTHORS

Prof. Harshad D. Santoki, PhD Scholar, Gujarat Technological University, Asst. Professor, Industrial Engineering Department, Lukhdhirji Engineering College, Morbi – 363 642. Gujarat. India.
Email: hdsantoki7@gmail.com

Dr. Ghanshyam D. Acharya, Principal, Atmiya Institute of Technology & Science, Yogidham Gurukul, Kalawad Road, Rajkot – 360 005, Gujarat, India
Email: gdacharya@rediffmail

Dr. Shailee G. Acharya, Asst. Professor, Mechanical Engineering Dept., Sardar Vallabhbhai Patel Institute of Technology, SVIT Road, Rajupura Village, Vasad, Anand – 388 306, Gujarat. India.
Email: shaileeacharya@gmail.com