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Application of the six sigma methodology in the area of paste preparation of a company in the ceramic sector

Aplicación de la metodología seis sigma en el área de preparación pasta de una empresa del sector cerámico

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ABSTRACT

Keywords:

Six sigma,
statistical process control,
process capability,
process improvement,
ceramic process,
measurements.

At present, there are a large number of quality improvement techniques, making it difficult for companies to decide which to apply. In this research, the paste preparation area of a ceramic tile manufacturing company was studied, and the result of this stage is directly reflected in the quality of the final product. The general objective was to apply the Six Sigma methodology in the paste preparation process of a ceramic company; likewise, to evaluate the measurements of the variables that intervene in the paste preparation area of the productive process of a ceramic company and the causes that affect the quality. The application of the six sigma methodology requires the application of statistical tools because the term sigma represents the standard deviation of a distribution and is key to know its variability [1]. The implemented methodology is the one proposed in the DMAMC cycle: Design, Measurement, Analysis, Improvement, and Control or DMAIC (Define, Measure, Analyze, Improve, and Control). The critical quality variables were established for each of the three stages of the pasta preparation area: raw materials, grinding, and atomization. The data obtained in the technological tests were organized in tables and graphs, to analyze the results qualitatively and quantitatively, using Minitab and SPSS. As a result, the evaluation of the paste preparation area is obtained, as well as the processing capacity of the different variables of the raw material stage, which exceeds 95%, except for the variables of loss by fire and viscosity. As for the grinding stage, the variable viscosity ($Z = 1.45$), with a processing capacity equivalent to approximately 85%. There are statistically significant differences. Finally, the variables of the atomization stage have a higher process capacity, 98%.

RESUMEN

Palabras clave:

Seis sigma,
control de procesos estadísticos,
capacidad del proceso,
mejora de procesos,
proceso cerámico,
mediciones.

En la actualidad, existen un gran número de técnicas de mejora de la calidad, por lo que resulta difícil para las empresas decidir cuál aplicar, en esta investigación se estudió el área de preparación pasta de una empresa fabricante de baldosas cerámicas, el resultado de esta etapa se ve reflejado directamente en la calidad del producto final. Se planteó como objetivo general, aplicar la metodología Seis Sigma en el proceso de preparación de pasta de una empresa cerámica; asimismo, evaluar las mediciones de las variables que intervienen en el área de preparación pasta del proceso productivo de una empresa cerámica y las causas que afectan la calidad. La aplicación de la metodología seis sigma requiere de la aplicación de herramientas estadísticas, esto debido a que el término sigma, representa la desviación típica de una distribución y es clave para conocer su variabilidad (Sharma, Bhardwaj, & Kumar, 2013). La metodología implementada, es la propuesta en el ciclo DMAMC: Diseño, Medición, Análisis, Mejoramiento y Control o DMAIC (por sus siglas en ingles Define, Measure, Analyze, Improve, Control). Se establecieron las variables críticas de calidad de cada una de las tres etapas del área de preparación pasta: materias primas, molienda y atomización. Los datos obtenidos en los ensayos tecnológicos fueron organizados en tablas, se empleó Minitab y SPSS y analizaron los resultados de forma cualitativa y cuantitativa. Se obtiene como resultado la evaluación del área de preparación pasta, así como la capacidad del proceso de las diferentes variables de la etapa de materias primas, las cuales superan el 95%, excepto para las variables de pérdida por fuego y viscosidad, se evidencian diferencias estadísticamente significativas. En cuanto a la etapa de molienda, la variable viscosidad ($Z=1,45$), con una capacidad del proceso equivalente aproximadamente al 85% y finalmente, las variables de la etapa de atomización cuentan con una capacidad del proceso superior, del 98%.

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Introduction

In recent years, companies and organizations around the world are showing great interest in quality. This is why the six sigma methodology has been adopted in various organizations to improve their performance through the use of statistical analysis techniques [1]. These statistical methods have a fundamentally important role to play in this process: sigma process measurements, quality-critical metrics, defect measurements, and process capability [2]. The difference between other improvement methodologies and Six Sigma lies in the reduction of variation [3].

However, apart from using statistical methods, the six sigma methodology expands its definition to three levels: Metric (Amount of deviation that exists in a data set: normal standard distribution); Methodology (Management of customer requirements, alignment of processes to achieve requirements and data analysis to minimize variations in these processes) [4]; and Management System (Apply it as a management system for the execution of the business strategy) [5].

Companies have been forced to adapt to new challenges from customers, who are becoming more and more demanding, which implies increasingly efficient products and services [6]. Which has led to the study and application of the six sigma methodology as a systematic and structured strategy, which according to [7], after two decades of successful application in the manufacturing industry, it is approved as an effective methodology for quality improvement and a long-term commitment.

A "high" sigma quality level means that defects are less likely to occur, while a "low" sigma level is more likely to occur. The Six Sigma level means that only 3.4 defects will be found for every million units produced considering the long-term capacity of the processes. [8]. That is, the area that lies within the limits between $+3\sigma$ and -3σ would be 99,9997% [9].

The Six Sigma methodology leads to the continuous improvement of processes by reducing the probability of defects, errors, or failures in the manufacturing or service processes, depending on where it is applied, the tendency is to have a controlled process with a standard deviation of six sigma. The application of this technique in all the functions of the company leads to a high level of quality at low costs and with a reduction in the cycle times of the operations, which add value; achieving high profitability and competitive advantage of the business [10]. The main characteristics of the six sigma methodology are: Achieve quality products and / or services, the client is established as a priority, takes into account data: which is collected and analyzed, and the participation and commitment of the personnel involved [11].

In Colombia, the ceramic and clay industry represents one of the links in the construction and decoration sector where approximately 6,085 direct jobs are generated [12]. In this sense, the National Association of Entrepreneurs of Colombia (ANDI) states that in the ceramic sector there are immediate needs to improve this important engine of the national economy such as environmental performance, productive chain, logistics, and transportation of the finished product, as well as the industry performance.

After studying the improvement methodologies through literature reviews in specialized databases, it was identified that most of the reported cases use statistical data to describe and even analyze the quality characteristics of the finished product. Consequently, six sigma was used as a pilot test of its implementation in the area of preparation of ceramic company paste where aspects for improvement were identified.

Materials and methods

The methodology was implemented through the DMAIC cycle, which provides an adequate framework to guide the improvement process in five stages [13], where each of these has activities and tools for its execution, in order to identify the process, evaluate the stability, capacity and measurement systems, identify real causes that affect the process and identify and select solutions in a stage of the ceramic process.

Stage I: Define Opportunities

Step 1. Process description

For this research, the production process of the pasta preparation area starts from the storage of raw materials in the company's yard (organized into 4 yards for clay material, 2 boxes for feldspar, 1 box for limestone, 2 boxes for cooked breaking, and 1 box for raw breaking), followed by dosing and weighing of raw materials in the tilting hopper according to the formulation of the paste, then the grinding stage (where it is homogenized and the size of the particle and formula compensation is carried out, which is carried out in drum or batch mills) and ends with atomization (drying process where the slip: liquid mixture of clayey and non-clayey materials, it is pulverized into fine droplets, it comes into contact with the hot air from the generator to obtain a product of constant humidity, granular, formed by small hollow spheres).

Step 2. Problem overview

The company had ceramic defects (mismatches, gauges, deformations, black heart) influenced by alterations in the variables of the previous stages of the tile shaping process. When analyzing the first stage: Raw materials, it was evidenced poor handling of raw materials causing waste per load (pollution). Likewise, there is a lack of control in the exploitation and homogenization of clays in the mines, which causes variation in the physical-ceramic conditions of contraction, water absorption, losses due to fire, and dimensional instability, which is directly related to rheological behavior of the slip.

Continuing with the milling stage, high consumption of electrical energy was found, which represents approximately 10% that the plant consumes. Finally, in the atomization stage, there is variation in the granulometry of the atomized powder and the percentage of humidity, these quality problems are reflected in the finished product.

The identifiable variables in each area of this stage are different and their relationship to each other can only be estimated from the information obtained in the process; Due to the above, the use of statistical tools (regression models, control charts, and ANOVA) is proposed to estimate the relationship models and the variability results from the process data, ensuring that the data come from stable situations and are statistically significant.

Step 2. SIPOC. Process map

The SIPOC diagram "Suppliers, Supplies, Processes, Products, and Customers", describes the main tasks and activities of the process [14]. The SIPOC fulfills the function of providing a broad idea of the process, it should be clarified that for this project it has been developed to plan the pasta preparation area and delineate its context [15].

This tool defines:

• S (Suppliers): Provider or providers that provide the physical or information inputs necessary for the process to begin.

• I (Input): The raw materials and / or information that trigger the process.

• P (Process): Set of tasks that are carried out to carry out the entire process studied.

• O (Output): What results from the process and which is finally delivered to costumer.

• C (Costumer): It is defined as to whom the final product is directed.

In this particular case, the raw material suppliers were external and due to the confidentiality, that they handled with these inputs, some kind of approach could not be established; and internal customers, which are a part of the same production system. This tool makes it possible to highlight information that is relevant to the project, thus focusing on critical activities in the process.

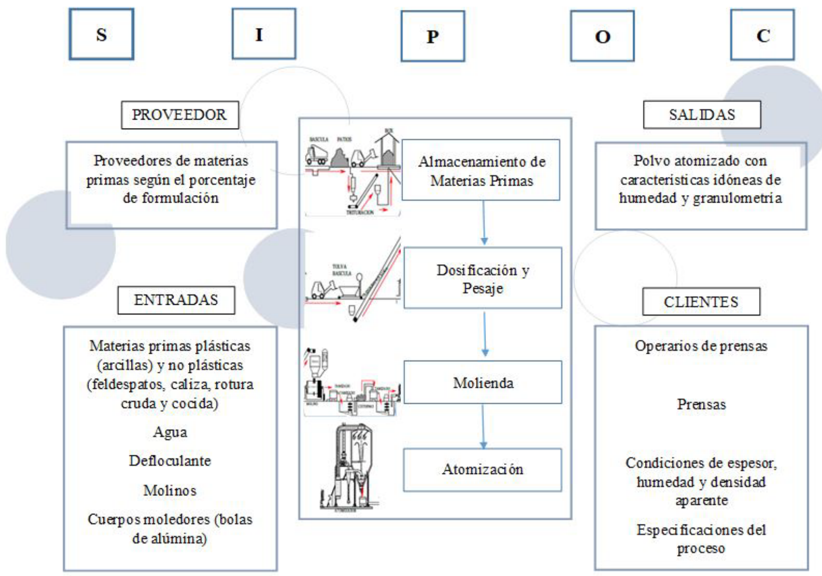

Figure 1. S.I.P.O.C for the pasta preparation area

Source: Author

Step 3. Select Critical Quality Variables

To determine the problems associated with the process, the tool is known as Value Stream Mapping (VSM) or mapping of the value chain that is used to collect and process data will be used, because this technique allows the stakeholders of an organization, visualize and understand the process, it also allows to recognize the value, differentiates it from waste and creates an action plan to eliminate it within the process [16].

• Raw materials: Percentage of Moisture, Shrinkage in cooking, Water absorption, Loss by fire, Percentage of Sands.

• Grinding: Density, Viscosity, and Residue.

• Atomization: Pumping pressure of the slip, Flow rate and temperature of the drying air, Granulometry of the atomized powder, Density of the atomized powder, the humidity of the atomized powder.

Step 4. Voice of the Customer

Internal customers include employees in the pasta preparation area. Various ways were used to capture the voice of the internal customer (obtain the needs established or not by the customer) through surveys and direct observations. Then the identification and prioritization of the requirements obtained is carried out.

A survey was designed, from the following question: What do the people who are in the processes say? Which was directed to the personnel of the pasta preparation area. An introduction to the subject was made to 6 operators who gave their opinions on the various factors that could affect each section of the pasta preparation area. All this to propose a work strategy that would allow achieving the project objectives.

Table I. Identification of ideas concluded in the pasta preparation area

Identification of the concluded ideas
o **Raw Materials**
High moisture content in raw materials due to atmospheric conditions, because the number of boxes is not sufficient to contain the variety of raw materials used in the formulation, so it is necessary to adapt spaces in the patio to unload raw materials and then covered with plastics, these sometimes do not cover what is necessary.
o **Grinding**
Due to the above condition, when the raw materials reach the grinding stage they cause agglomerations that wear more mills.
This stage is the one that generates the most noise and pollution of the entire production process, the operators use all the required personal protection elements, and a few hours of cleaning the platforms and the surface have been established.
o **Atomization**
Variation of the humidity of the paste, this because there is an increase in the humidity of the atomized powder as the pressure of the slip increases.
This is because the increase in pressure leads to an increase in the flow rate of the slip inside the atomizer.
Constant changes in operating conditions: changes from a gas to fuel oil.

Stage II: Measure the system

This phase seeks to acquire data to validate and quantify the problem / opportunity, as well as to identify the cause of the problem, as well as to calculate the initial sigma measurement of the process [17]. It is the key transition phase, as it serves to validate the problem and begin the search for causes [14].

The key concepts in this phase are: Measurement (apply the metrics and determine the performance of the process), Variation (present in any process), Information (collection of measurements over time), and Data collection plan (method to obtain the data) [18].

Step 1. Data collection plan

The data collection plan shows the information related to the process, its objective is to collect all the data that can help determine the variables that affect the process of the pasta preparation area.

Raw Materials: Physico-ceramic analyzes are carried out on the raw materials for consumption and the formulation of the paste once a day. Parameters: Laboratory 3.90-4.0 (%), Production (3.70-3.75). Variations < 1%

Grinding: A sample was taken per mill, generally, 5 mills operate and two mills are carried out per shift, for a total of 10 mills. This depends on the operating condition of the mill. Parameters: Density: 169.0 to 169.5 (1), 168.0 to 168.5 (2), Viscosity: 18-20 (performed with Ford Cup) and Residue: 10-10.5 (1) / 10-10.2 (Mesh sieve 230) (2).

Atomization: In the atomizers every 30 minutes and in the storage silos every shift.

Moisture percentage: Period (1) ATE 90: 5.6-5.8. Silos: 5.4-5.8
Period (2) ATE 90: 5.8-6.1. Silos: 5.6-5.9

Granulometry: 20 mesh (0-0.9%), 40 mesh (21-28%), 60 mesh (48-54%),
80 mesh (12-16%), 120 mesh (5.5-7.5%) and collector (3,5-5,5%).

Temperature: 500 ° C (ATE 90 inlet), 90-93 ° C (ATE 90 outlet) and 340-
350 ° C (Sheet metal (cone body)

Step 2. Statistical Process Control (SPC)

o Quantification of Zscore and DPMO (Baseline measurement)

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The dependent variables to be measured in each of the stages of raw materials, grinding and atomization of the pasta preparation area, are quantitative variables expressed in the respective unit of measurement, for which a descriptive analysis was performed on each one, the control charts and estimation of the sigma level.

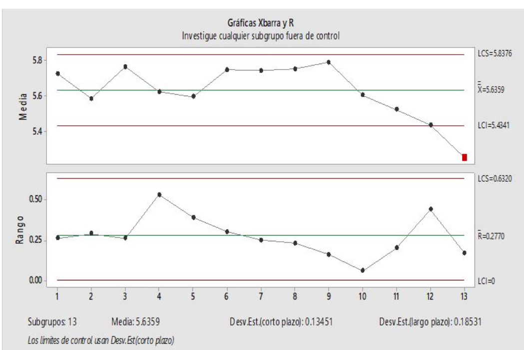
Analysis of Variables Associated with the Raw Materials Stage

• Random sample

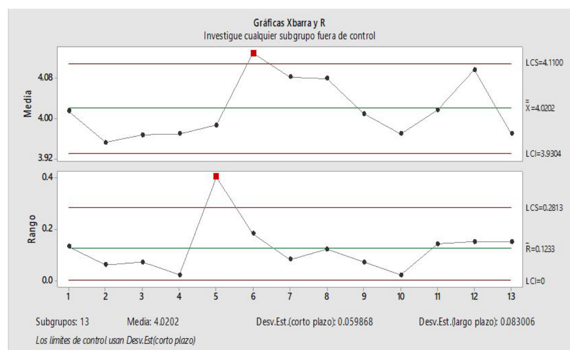
Given that the two-month data were available, the total number of records collected was fifty-one (51), this is significantly lower compared to the data obtained in the grinding and atomization stages, the above because The company provided the data for the formulations and not for each of the raw materials that comprise it, as it is considered confidential, which is why there are 25 records for August and 26 for September. For the analysis, each of the levels of the factors or dependent variables of this process have been considered. Factors: Formula, Water absorption (Aa), Flexural Strength (RF). Dependent variables: Losses due to fire (PPF) and Percentage of shrinkage in cooking (% CC). Taking into account the above, for this process, simple random sampling is not used and the 51 records observed are considered.

o Control charts

Considering the different levels of the categorical independent variables (Factors), 4 measurements were taken by groups of three (3) or four (4) days, approximately one (1) daily measurement. In this sense, four (4) are taken as the size of the subgroup to make the control charts, the XBar-R charts are made. The results of the variable losses due to fire are shown in Graph 1 and the results of the variable percentage of shrinkage in firing are shown in Graph 2.



Graph 1. Control Graph for Losses Due to Fire PPF
Source: Own elaboration from Minitab



Graph 2. Control graph Percentage of Shrinkage in Cooked (% CC)
Source: Own elaboration from Minitab

Graph 1 shows the mean of the process for the PPF variable, which may not be stable. 1 subgroup (7.7%) is out of control on the Xbar chart. There is the possibility of seeing 0.7% of subgroups out of control, although the process is stable, specifically Subgroup 13 represented by a mean of 5.25. The overall behavior can be classified as cyclical. In reference to Graph 2 (% CC), the mean and the variation of the process could not be stable. A subgroup (7.7%) is out of control on the Xbar chart. A subgroup (7.7%) is out of control on the R chart, which could affect the validity of the control limits on the Xbar chart.

There is a possibility that 0.7% of subgroups are out of control on the Xbar chart and 0.5% of subgroups are out of control on the R chart, even though the process is stable. It was decided to investigate subgroups out of control and omit those with special causes from the calculations. This situation allowed us to review the outliers in subgroup 5

(Range 0.4) and 6. (Mean 4, 13).

o Descriptive Analysis

Table 1 shows the descriptive statistics for the variables: PPF and% CC of the Raw Materials process.

Table I. Descriptive statistics for the variables of the Raw Material process

PPF	Media	5.64
	DE	0.19
	Med	5.65
	Min	5.18
	Max	5.87
	P25	5.48
	P75	5.80
PORCC	Media	4.02
	DE	0.08
	Med	4.00
	Min	3.85
	Max	4.25
	P25	3.96
	P75	4.08

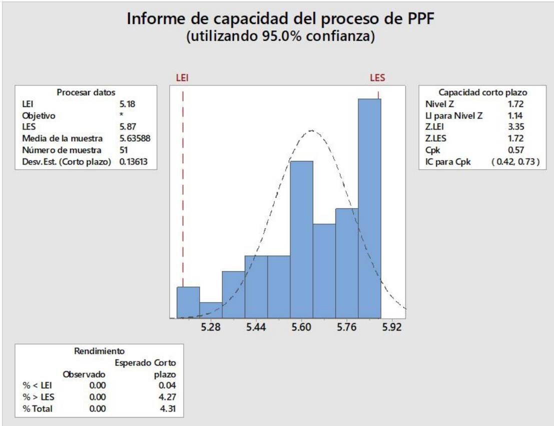
Source: self-made

Losses due to fire in the process show an average of 5.64% with a 95% confidence interval that ranges between 5.58 and 5.68. The variability of the set is low and reaches 0.19%. 50% of the mediations reached values above 5.65%, while the central 50% reached values between 5.48 and 5.80%. Regarding % CC, the mean is 4.02% with a 95% confidence interval that ranges between 3.99 and 4.04 and low variability of less than 0.09%. On the other hand, 50% of the measurements reached values above 4.00; while the central 50% reached values between 3.96 and 4.08. The range of the data for% CC reached 0.4 units, pointing to a maximum of 4.25 and a minimum value of 3.85%.

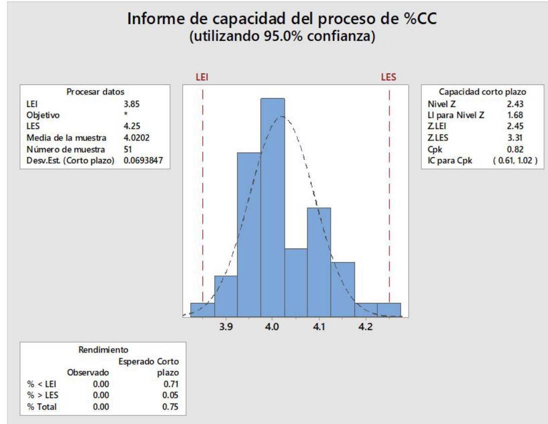
When analyzing the dispersion of the data that are out of control, these results can be attributed to atypical movements (special causes of variation), however, when analyzing their variability concerning the variation coefficients, variability values of 3.36 are found%, 1.99%, and 2.90% respectively, indicating that once the cases out of control have been eliminated, the general set of data is quite homogeneous.

o Sigma Level of the Variables: PPF and% CC

To estimate the sigma level of each of the dependent variables PPF and% CC, a short-term analysis is carried out considering a subgroup size of 4 and lower limits of 5.18% and upper limits of 5.87% for PPF and 3.85% (Lower) and 4.25% (upper) for% CC. The units in both cases are shown in percentages, see Graphs 3 and 4.



Graph 3. Calculation of the sigma level for PPF
Source: Own elaboration from Minitab



Graph 4. Calculation of sigma level for% CC
Source: Own elaboration from Minitab

For the PPF variable, a level Z = 1.72 is reached, a value that indicates that the process capacity exceeds 90%, while the% CC the process capacity exceeds 98% (Z = 2.43).

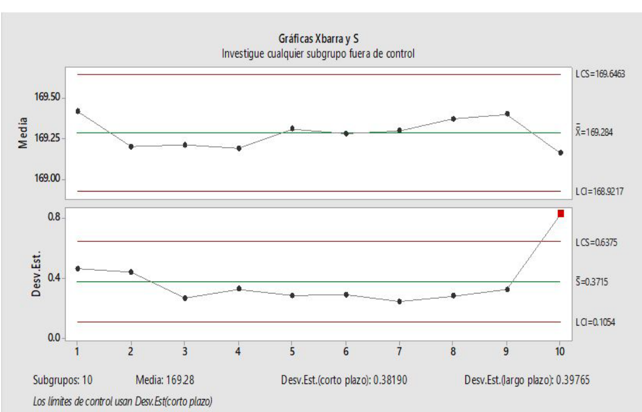
Analysis of Variables Associated with the Grinding Stage

o Ramdom Sample

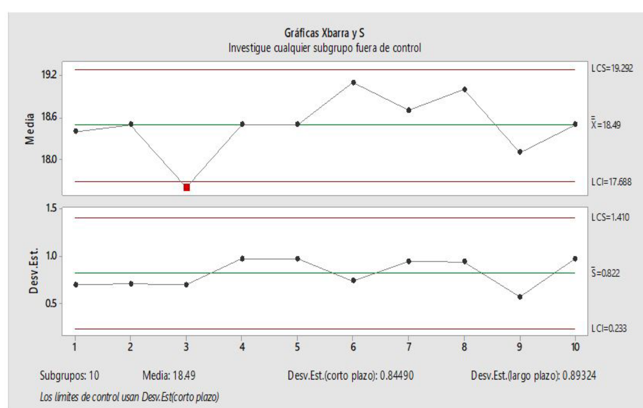
Given that the data were available for the periods of August and September, the total number of records collected was 700, each of the levels of the factors or dependent variables are taken into account, see Table 1. In this way considering a 95% confidence interval and a maximum error of 5.5 points, a work sample of size 100 was obtained by simple random sampling. From this data set, the control graphs, descriptive analysis and the estimation of the sigma level were carried out.

o Control Graphs

After considering the different levels of the categorical independent variables (factors), 10 measurements were taken per shift, approximately 20 daily measurements when working two shifts or 30 observations for days with 3 shifts. In this sense, ten (10) are taken as the size of the subgroup to make the control charts, consequently, the XBar-S Graphs are made. The results are shown in Graphs 5 and 6.



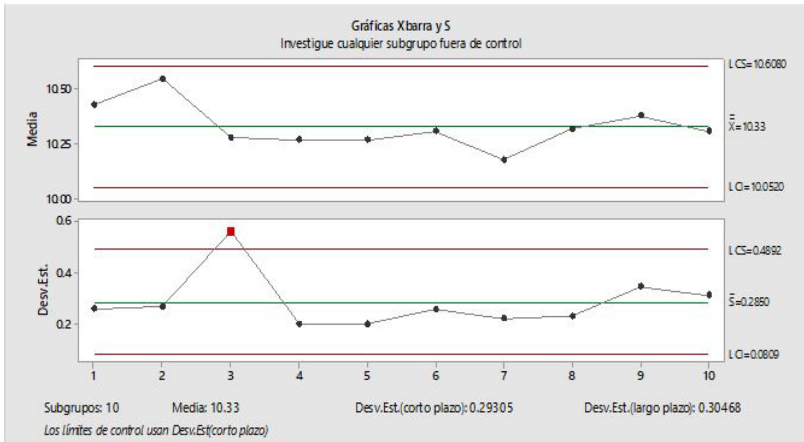
Graph 5. Control graph for Density
Source: self made



Graph 6. Control graph for Viscosity
Source: self-made

Graph 5 shows that the process mean for the Density variable is stable, this because no group is out of control. About Graph 6 for the Viscosity variable, the process means may not be stable since there is 1 subgroup (10.0%) that is out of control in Graph Xbar-S, this situation indicates that they review the outliers in subgroup 3.

Graph 7 shows the control charts of the evaluated sample for the Residual variable, in the figure it can be inferred that the mean of the process is stable. No subgroups are out of control in the Graph Xbar.



Graph 7. Control graph for Waste
Source: self-made

o Descriptive Analysis

Table 2 shows the descriptive statistics for the variables: Density, Viscosity, and Residue of the Grinding process.

Table II. Descriptive statistics for variables of the Grinding process

	Media	DE	Med	Min	Max	P25	P75
Density	169.28	0.40	169.30	167.00	170.10	169.10	169.50
Viscosity	18.49	0.89	18.50	17.00	20.00	18.00	19.00
Residue	10.33	0.30	10.30	9.60	11.40	10.10	10.50

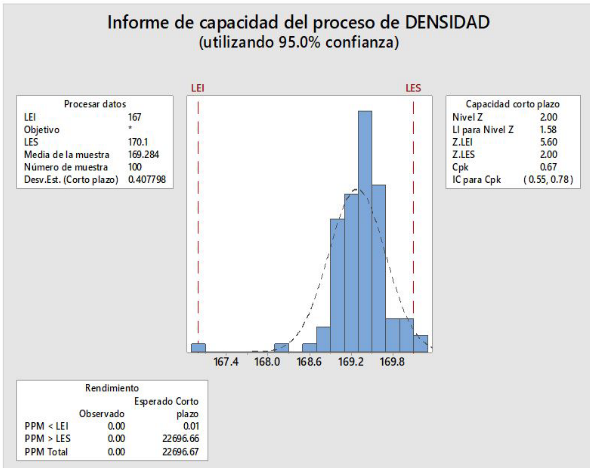
Source: self-made

The density of the process presents an average of 169, 28 g/cm3 with a 95% confidence interval ranging from 169,2 g/cm3 and 169,36 g/cm3. The variability of the set for density is low and reaches 0.4g/cm3. 50% of the mediations reached values above 169,30 g/cm3, while the central 50% reached values between 169.10 and 169,50 g/cm3. The data range for Density exceeded 3 units, pointing to a maximum of 170.10 g/cm3 and a minimum value of 167 g/cm3.

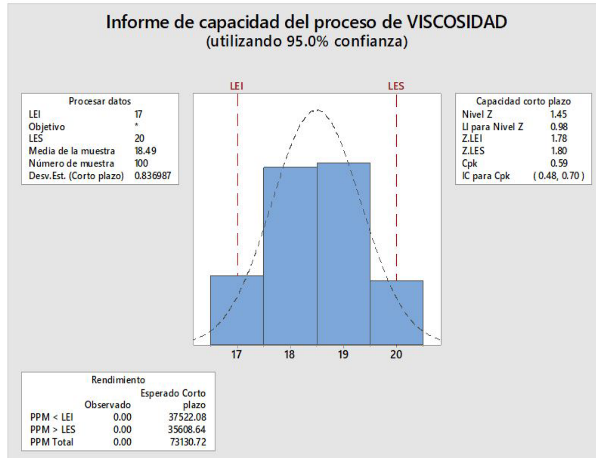
When analyzing the dispersion of the data that are out of control, these results can be attributed to atypical movements (special causes of variation), however, when analyzing their variability concerning the variation coefficients, we find variability values of 0.2. 3%; 4.81% and 2.90% respectively, indicating that once the out-of-control cases have been eliminated, the general set of data is homogeneous.

o Sigma Level of the Variables: Density, Viscosity, and Residues

To estimate the sigma level of each of the dependent variables: Density, Viscosity, and Residues, a short-term analysis is carried out, considering a subgroup size of 10 and lower limits of 167 and 170.10 for Density, for Viscosity 17 (Lower) and 20 (upper) and the variable Lower limit residual of 9.60 and upper limit of 11.40. The results are shown in Graphs 8, 9 and 10.



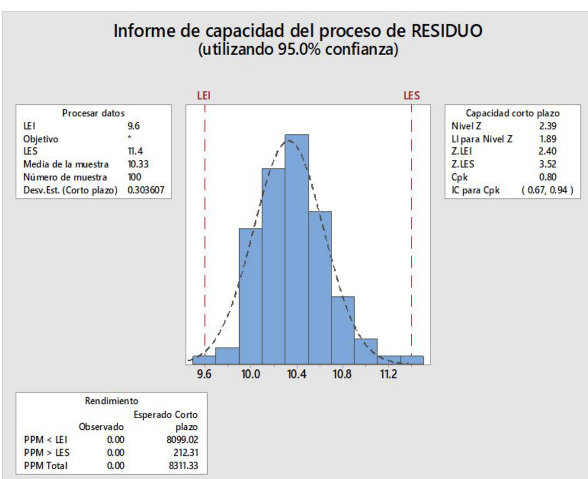
Graph 8. Calculation of the Sigma Level for the variable Density
Source: Own elaboration from Minitab



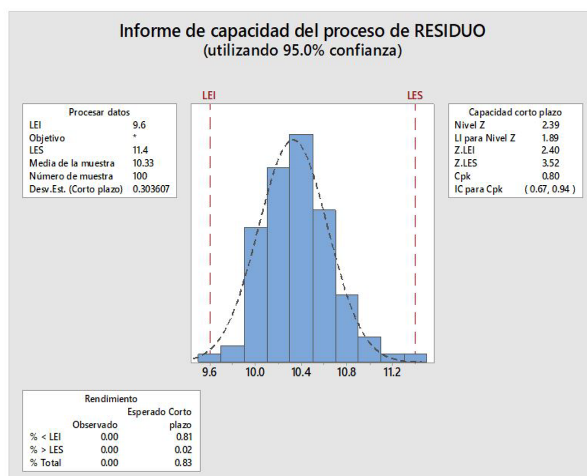
Graph 9. Calculation of the Sigma Level for Viscosity
Source: Own elaboration from Minitab

When analyzing the sigma levels, it is found that the Density variable reaches a level Z = 2.00, a value that indicates that the processing capacity exceeds 96%, while for the Viscosity variable this capacity is decreased (Z = 1, 45) with a processing capacity equivalent to approximately 85%. Concerning the dependent variable Waste, the value of Z equals 2.39, which represents a high capacity of the process above 98%.

The Cp index is designed to measure the degree of global variation of the process (does not depend on the process mean), while the Cpk index, shows the impact of the processing capacity and identify how close the process is within the specification limits [19].



Graph 10. Calculation of sigma level for PPM residue
Source: Own elaboration from Minitab



Graph 11. Calculation of the Sigma Level for Waste
Source: Own elaboration from Minitab

Analysis of Variables Associated with the Atomization Stage

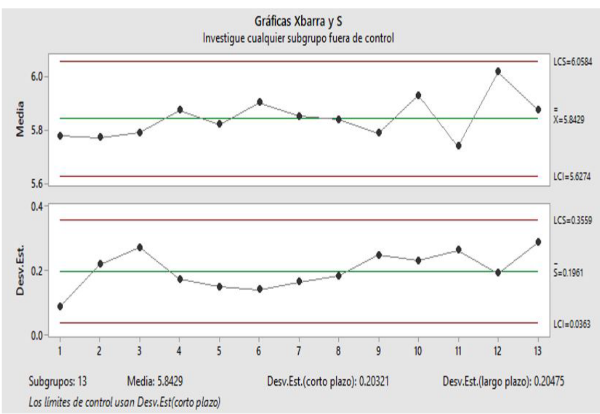
o Random Sample

Given that the complete records were available for the periods of August and September, the total number of records collected was 869, each of the levels of the factors or dependent variables in this process were considered, which are shown in Table 3 (Factors: Shift, Fuel Type, Slip Pressure, Inlet and Outlet Temperature of the ATM 90 atomizer. Dependent variables: Percentage of Moisture and Percentage of Mesh Granulometry 60).

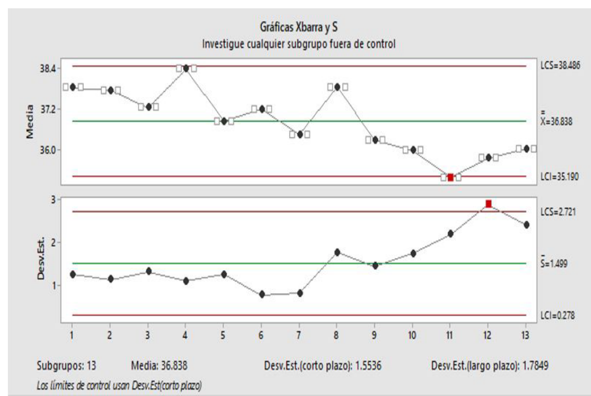
In this way, considering a confidence interval of 95% and a maximum error of 5.5 points, a working sample of size 100 was obtained by simple random sampling. From this data set, the control graphs, descriptive analyzes and the estimation of the sigma level were carried out.

o Control Graphs

Considering the different levels of the categorical independent variables (Factors), 8 measurements were taken per shift, approximately 16 daily measurements when two shifts were worked, or 24 observations for days with 3 shifts. Therefore, eight (8) are registered as the size of the subgroup to make the control charts, consequently, the Graphs XBarra-S are made, see Graph 12 and Graph 13.



Graph 12. Control graph Moisture percentage
Source: Own elaboration from Minitab



Graph 13. Control graph Percentage of Granulometry
Source: Own elaboration from Minitab

Graph 12 shows that the process means for the variable Moisture percentage is stable since no group is out of control. About Graph 13 (Granulometry Percentage), the mean of the process may not be stable since there is 1 subgroup (7.7%) that is out of control in Graph Xbar-S, this situation indicates that the outliers should be reviewed in subgroup 11. The mean and the process variation may not be stable.

One (1) subgroup (7.7%) is out of control on the Graph Xbar. 1 subgroup (7.7%) is out of control on Graph S, which could affect the validity of the control limits on the Graph Xbar. There is a possibility that 0.7% of subgroups out of control will be observed in Graph Xbar and 0.3% of subgroups out of control in Graph S, even though the process is stable. Out-of-control subgroups should be investigated and those with special causes omitted from the calculations.

o Descriptive Analysis

Table 3 shows the descriptive statistics for the variables: % Humidity and% Granulometry involved in the Atomization process. The mean granulometry percentage is 5.84% with a confidence interval between 5.80% and 5.88%, the variability that this variable presents is low and is equivalent to 0.20%. 50% of the observations for this variable reached values above 5.81%, while the central 50% reached values between 5.7% and 6%. The range of the data for the Percentage of Moisture exceeded the unit, pointing to a maximum of 6.35% and a minimum value of 5.30%.

Table 3. Descriptive statistics for the variables of the Atomization process

	Media	DE	Med	Min	Max	P25	P75
% of humidity	5.84	.20	5.81	5.30	6.35	5.70	6.00
% of granulometry	36.84	1.78	36.90	29.20	40.60	36.00	38.05

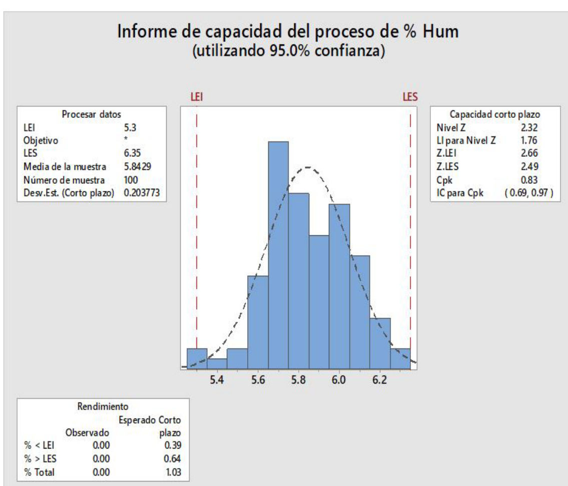
Source: self-made

Regarding the Granulometry percentage, the mean value is 38.84% with a 95% confidence interval for the mean that ranges between 36.48% and 37.19%. The standard deviation for this variable is 1.78%, evidencing a high homogeneity between the set of measurements of this variable. The central 50% of the measurements range between 36 and 38.05%. The approximate range for this variable is approximately 10%.

When analyzing the dispersion of the data that are out of control, these results can be attributed to (special causes of variation) atypical movements, however, when analyzing their variability concerning the variation coefficients, variability values of 0.03 are found% and 0.04% respectively, indicating that once the out-of-control cases have been eliminated, the general set of data is quite homogeneous.

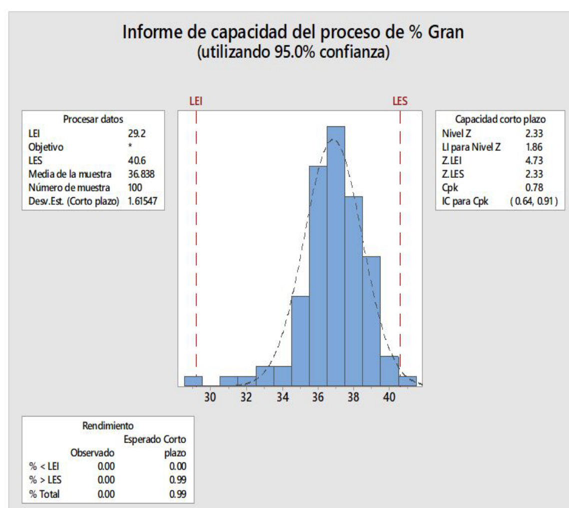
o Sigma Level of Variables: % Moisture and% Granulometry

To estimate the sigma level of each of the dependent variables: % Humidity and% Granulometry, a short-term analysis is carried out considering a subgroup size of 8 and lower limits of 5.30% and 6.35% for the Humidity, for the Granulometry: 17 (lower) and 20 (upper) and for the variable Lower limit residue of 29.20% and upper limit of 40.60%. The results are shown in Graphs 14 and 15.



Graph 14. Calculation of the Sigma Level for Percentage of Moisture

Source: Own elaboration from Minitab



Graph 12. Calculation of the Sigma Level for Percentage of Granulometry

Source: Own elaboration from Minitab

Interpreting the sigma values for% Humidity, we have a value of Z = 2.33. On the other hand, when evaluating the variable% of Granulometry, a value of Z equivalent to the% of Humidity (Z = 2.33) is found, indicating for both variables, a higher processing capacity around 98%.

Stage III: Analyze the root causes

It is the third stage of the DMAIC cycle, where the data collected in the measurement stage are examined to generate a priority list of sources of variation. It is the most unpredictable stage of the process, as it becomes a detection process [14].

Fishbone Analysis

It was built to synthesize the most influential and common factors that occur in the pasta preparation stage, see Table 4. However, due to company limitations, some variables generated such as the wear of the grinding bodies (alumina balls) and the Characteristics of the raw materials could not be controlled, because the raw materials are handled under confidentiality and only the formulations could be analyzed. It was built from the interview carried out and observations of the process.

Table 4 is constructed based on the 6M method, which consists of grouping the potential causes into six main branches: Labor, Machines, Materials, Work Methods, Measurement and Environment [20].

Table IV. Possible causes that affect the Pasta Preparation Area

Number	M	Causes
1	Method	Deflocculant and water variation
2	Workforce	Lack of staff to clean the area
3		Direct sun exposure in the raw materials yard
4		Slower work rate due to physically demanding activities
5	Environment	Atmospheric conditions (rains)
6		High level of noise and pollution
7	Measurement	Lack of calibration of deflocculant pumping systems
8		Atomizer operating conditions
9	materials	Variation in size of raw materials
10		High moisture content of raw materials
11		Variation of humidity of the pasta
12		Contamination with lubricants or carbon debris
13	Machine	Mechanical failures
14		Leakage in conveyor belts and elevators
15		Gate missing in silos: segregation of material during loading into the silo
16		Downspout in the mills in poor condition
17		Pump failures

Source: self-made

Stage IV: Improve

In this stage, alternatives for improvement are developed, for this, the brainstorming tool is of great help, where, based on ideas contributed by the different participants, the different solutions for each cause in the previous table can be defined.

Potential actions related to the identified causes:

o Implement the SMED tool. (Single minute Exchange of Die) "The change in a single minute before finishing" to maximize the use of the company's available equipment or machines and thus obtain greater control of the data obtained.

o Design and implement a training plan for the personnel in charge of operating the mills, supported by the topics of personnel roles, the flow of the paste preparation process, equipment maintenance, measurement system for inputs in the milling stage.

Stage V: Control

It is the last stage of the cycle, definitive improvement plans are established, taking into account that they are permanent over time and that these defects are not generated again in the process as far as possible. At this stage, it is necessary to have the proper documentation and it would be necessary to collect information again to study if the improvement has been effective, it is highlighted that the actions implemented during the investigation, generated a change in the attitude of the personnel of the pasta preparation area, due to the continuous monitoring of the results.

o Implementation of a new atomizer, which replaces the most inoperative atomizers to optimize the paste preparation process and thus avoid the use of coal, which causes pollution to the atmosphere.

o Strengthen the Product Development and Innovation department, it is necessary to create new materials in terms of design, textures, and alternative raw materials.

o Establish work parameters for each of the different formulations used by the company.

o Define the optimal starting conditions for the atomizer.

Results and Analysis

The result of the preliminary analysis was carried out using statistical control letters, from which it is observed that the process presents cyclical behavior and that some points are above the limits, which at any time can get out of control.

In turn, the capacity of the process was calculated where it shows that in the different variables studied in the pasta preparation area it exceeds 95%, except for the variables of losses due to fire (PPF) with 90% and the variable viscosity (V) with the 85%.

It was found in the normality test carried out (the p-value is $0.04 < 0.05$) that indicates that the viscosity in the grinding stage varies in each of the mills, that mill 5 produces a higher average viscosity compared to other mills. This shows that the averages of the water levels are not significantly different in the variables considered.

On the other hand, in the atomization stage, the percentage of granulometry concerning the 60 mesh must be checked with special care. Likewise, the temperature levels between 91 and 96 degrees, the present average percentages of granulometry lower than the temperature levels of output between 86 and 90 °C.

Conclusions

The Six Sigma methodology, as it is based on statistics, allows effectively detecting deviations based on a norm or a standard, which allowed to obtain the monitoring of the paste preparation area of a ceramic company. The Six Sigma methodology, as it is based on statistics, allows effectively detecting deviations based on a norm or a standard, which allowed to obtain the monitoring of the paste preparation area of a ceramic company.

The integration of statistics to the pasta preparation area, through stability and capacity studies, allowed to have stricter quality control. Communication within the company is essential for the application of the Six Sigma methodology, to ensure the success of its implementation it is necessary to involve all staff.

Through the DMAIC method, a clearer definition of the company can be obtained, since a broad analysis of the different stages of a process is carried out. The methodology may be applied in other parts of the process such as pressing, enameling, firing, and storage and even in other companies in the ceramic sector.

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