The Evaluation of Defects in the Aluminium Extrusion Process Through Quality Tools

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Abstract: - In the aluminium industry, the chain of processes is long and involves different operations, starting with operations related to the extractive industry and ending with the piece of aluminium that would be sold. To make this process solid, viable and competitive, companies involved need to base their decisions on a consistent set of data, which enables them to obtain workable information throughout the process and thereby reduce, or eliminate, the percentage of defects that occur.

During the aluminium extrusion, defects are largely responsible for decreasing the quality of the finished product (profiles) which requires the duplication of work. Thus, defects lead to increased production costs, delays in delivery and increase of the scrap percentage.

This work, resorting data previously collected in an industry in this area, aims to classify and quantify the defects that occur throughout the extrusion process. To identify the causes, to correct possible deviations, to find solutions and improvements are used several quality tools in particular: Brainstorming, Pareto Diagram, Ishikawa Diagram, Histogram and Control Chart.

Above all, the purpose of using these tools is to provide operators and managers with adequate indicators, which allow the control of the production process and the identification of critical extrusion variables or others, responsible for excess waste, defects and, consequently, in order to increase productivity.

During the execution of this work, the defects of the extrusion process were typified and quantified, and whose causes and possible corrective actions were studied. Through the obtained results, it is clear that the "bubble" defect represents a very significant part of the total defects studied, which revealed the pertinence of the monitoring of this defect.

During the study we conclude that there are several variables, which affect the appearance of the "bubble" defect. Then, some control charts of the main variables are performed, in particular for the time at the maximum extrusion pressure and the temperature of the container.

Key-Words: - Extrusion, Aluminium, Statistical Process Control, Quality Control

1 Introduction

The economy internationalization combined with the growing demand for aluminium by the world's major powers is leading to an increase in competition and competitiveness among companies involved in aluminium extrusion.

Nowadays, the product of a company has competition from several companies around the world since we live in a digital era where the media and transportation create a global market [1]. As a result, companies are forced to develop new processes with a focus on how they manage the raw material to the finished product and how they create a stable relationship with the customer. This way of thinking is crucial to ensure that companies can build sustainable and durable businesses and that their products are sold in the present and future.

However, the probability of companies surviving and developing is affected if there is no constant concern for the continuous improvement of their processes, aiming at reducing costs and waste. Clearly, combating waste is a goal to be achieved [2]. One way to identify waste is to keep the process under control, and to control it, you need to know the whole process. Since "keeping under control is knowing how to locate the problem, analyse the process, standardize and establish control items in such a way that the problem never happens again" [3]. This is the only way to increase productivity, because "to produce more and more and/or better with less and less" [3].

In this way, the reduction of the level of quality defects and the manufacture of high quality products do not result from the inspection activities but fundamentally from the improvement activities process, making them more efficient, simpler, safer and, fundamentally, with less nonconformities, minimizing the quantity of scrap [4].

In the same line of some authors, which defines the concept of quality as being a consumer oriented approach and that this should be the starting point for an organization that wants continuous quality improvement [5]. On the other hand, associate the concept of quality with the concept of management and assign two definitions to it [6].

Quality defined through the level of consumer satisfaction (products according to specifications, or quality such as absence of defects (fewer defects = less costs) [7]. In order to meet the customer's needs, and to guarantee the delivery of the product according to its requirements, it is necessary to find solutions that allow the collection of information, along the entire production chain, and their analysis and use to a better decision-making. This can help companies to improve their operational efficiency and overall the quality of the product. Of the many Process Control (PC) tools available to ensure better quality control and optimum quality, Statistical Process Control (SPC) allows to optimize and monitor quality using the data created throughout the entire productive process.

The PC in its broadest sense is a collection of production methods, concepts, and management practices that can be used throughout the organization. The SPC resorts itself to the use of statistical signs to identify sources of variation, improve performance and maintain control of production at higher quality levels.

By using this type of quality tools, the critical points of each process can be determined. Thus, the identification of causes or potential causes that lead to the appearance of the defects, and the capacity of its detection, can help the definition and implementation of corrective solutions and preventive actions, which intend to eliminate the causes or potential causes of failure.

This work is based on data collected in the company ADLA Aluminium Extrusion S. A., and it is justified by the need of the company to constantly adapt to new markets and customer requirements, and to find better strategies in the conduct of operations/processes. This need arises from the verification of the existence of a high quantity of scrap, coming from defects in the extrusion.

Through the application of quality tools, it is intended to contribute to the reduction of the variability of processes and products quality and, consequently, to reduce production costs.

In the particular case of the aluminium extrusion industry, whose waste/scrap represents significant costs for the company, it was considered appropriate to implement a program to improve the quality of the process, based on the following objectives:

1. To define which types of nonconformities have the most impact on performance indexes and are most critical to the process.
2. To Identify the causes of nonconformities and to study possible corrective actions.

Thus, some quality tools were applied throughout this work, namely: Brainstorming, Pareto Diagram, Ishikawa Diagram, Histogram and Control Chart.

2 Quality Tools

The increase of information in an organization generates a growth in the need to apply tools that can compile and process data, in order to support effective decision making [8].

Quality tools are techniques that are used to define, to measure, to analyse and to propose solutions to problems that interfere with the good performance of the work processes [9].

According to Professor Ishikawa, 95% of a company's problems can be solved with the basic quality tools, and the key to problem solving lies in the ability to identify the problem and to use the appropriate tools, based on the nature of the problem and quickly communicate the solution to others [10].

Quality Tools consist of simple means for problem solving and can be used by all employees, promoting teamwork, since their visualization allows the understanding of all.

Although there are a great variety of quality tools, the most important are the seven basic quality tools, suggested by Ishikawa, namely [11]:

1. Cause and effect diagrams;
2. Pareto Charts;
3. Check sheets;
4. Flowcharts;
5. Histograms;
6. Scatter plots.
7. Control charts.

These techniques are usually referred as "the magnificent seven" (MS), since they are an important part of quality control, some of them, in particular, are designed by SPC [12]. The SPC is, therefore, a set of statistical methods, included in the quality control tools. From the MS, for example, the Pareto Charts tools, Check Sheets, Histograms, Scatterplots and Control Charts are considered SPC, since they involve statistical techniques. The SPC, as well as the other quality tools, consist in a set of

methodologies, which are usually called Control or Quality Management (QM) methodologies.
QM was born in the United States of America, but the Japanese were the ones who first understood its value, they imported it and implemented it. It was ignored for decades in America, while it helped Japan to become the world leader in quality. Only in the last two dozen years the West has rediscovered the SPC, to start the conquest for quality improvement [13].
The SPC comprises a powerful set of problem solving tools, which are very useful in order to ensure the stability of a given process and to promote the improvement of its capacity by reducing its variability [14]. This concept was introduced by Walter A. Shewhart, in the 1920s, when he proposed graphs or charts as the first tool to monitor the variability of a process [12].
This concept is of particular interest to industries, because of their applicability in monitoring the variability of manufacturing processes and consequently in the reduction of nonconforming products. Control chats involves the inspection of a random sample of the output of a process, and decides if the process is producing products with characteristics that are within a predetermined range.
The SPC allows us to know if the process is working correctly or not [12]. Although, however well designed the productive process may be, it will always be subjected to a natural variability which, when coupled with external factors, causes the process to be out of control [12].
Therefore, it is imperative to implement techniques to control the process, for example control charts, to monitor its stability, to reduce variability if necessary, and to determine if it is able to produce according to specifications [12].
Some of the QM techniques, in particular those used in this work, are briefly described below.

2.1 Cause and effect diagrams and Brainstorming

In any study of a problem, the effect - as a particular defect or a particular process failure, is generally known. Cause and effect analysis can be used to trigger all possible contributing factors or causes of the effect. This technique includes the use of cause and effect diagrams and brainstorming.
The Cause and Effect Diagram, also known as the Ishikawa Diagram or Fishbone Diagram, is a systematic way of listing and organizing all possible causes of a quality effect or problem [15]. It consists in the organization and presentation of ideas about possible reasons for a priority problem and its main effects, and works as the basis for finding solutions.
A horizontal arrow represents the effect. Arrows inclined towards the horizontal arrow present the main causes and horizontal arrows that touch the relevant main arrow of the cause, as shown in Fig. 1 represent the secondary causes.

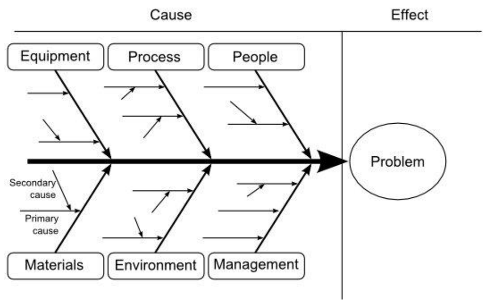


Fig. 1 – Cause and effect diagram [15]

2.2 Pareto Charts

To solve the unequal distribution of wealth in Europe, Pareto invented these graphs / diagrams, usually referred as Pareto Diagram or Pareto Chart.
He exposed the universal law called "80-20 law," which states that 80 percent of anything is attributed to 20 percent of its causes.
The Pareto diagram is a chart that organizes the data in descending order from left to right. The steps involved in its construction are the follows [15]:

1. Define the objectives and gather the necessary data.
2. Calculate the frequency distribution.
3. Sort the categories and calculate the cumulative distribution.
4. Draw the bars and the cumulative curve.

In the horizontal axis the different categories of defects are considered and in the vertical axis, the percentage accumulated. Categories can represent problems, causes and/or nonconformities. The purpose of this diagram is to highlight the problem, which must be examined first, because, it is the cause of the major number of problems.
The use of Pareto analysis is an infinite process, since it can be used to measure the progress of corrective action. It also helps to improve safety, to reduce waste, to conserve energy, to reduce costs, etc., analyzing the problems by different data groups and analyzing the before and after impact of the changes [15].

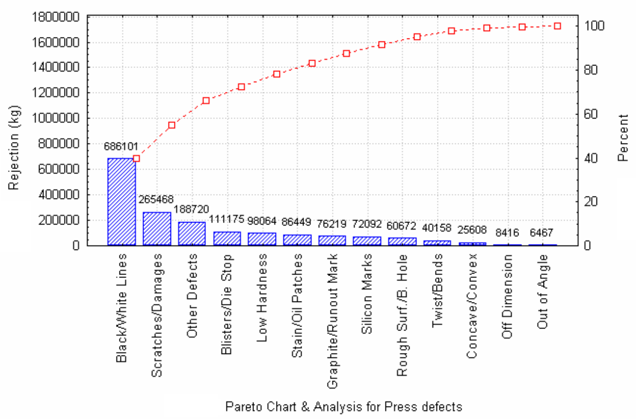


Fig. 2 – Pareto Chart for causes of default rejections [1]

Fig. 2 illustrates a Pareto Chart for causes of rejection due to defects caused during extrusion [1]. In this graph, it is observed that the most observed causes are lines, corresponding to about 40% of the defects verified. The 80% of rejections are reached in the fifth verified cause, in a set of 13. In this case, 5/13 represents about 38% of the causes accounting for 80% of rejections, which is not exactly in accordance with the "80-20 law", but effectively few "reasons" justify a larger part of the rejections, as Pareto said.

2.3 Check sheets

Check sheets are cross-reference tables or tables where occurrences are recorded. These instruments help with the recording of data and their subsequent analysis. They are considered the simplest quality control tools, for their simplicity.

By using this technique, it is possible to save time, because its read is easier, when compared with the direct reading of the data. For a better understanding of the state of the process, it is essential to collect data (both current and historical) of the process under analysis, thus, check sheets are very useful in this process of data collection [12].

Table 1 presents an example of a check sheet, used in surveying the occurrence of defects in the monthly production of a factory. These types of sheets allow analyzing evidences of eventual production problems.

Table 1 – Check sheet example

Defect type	Month	
	January	February
Bubbles	100	80
Lines	50	70
Crinkles	50	50

For example, according to this table it can be seen that the production of "Bubbles" type defects is the most frequent. Besides that, it decreased in January, while the "Lines" type defect has increased. This may indicate the resolution of one problem and the increase of another. Therefore, the check sheet has great application for surveying and checking data and facts

2.4 Flowcharts

The flowchart illustrated in Fig. 3 consists in a representation, which shows all phases of a process or procedure. It identifies the process flow as well as the interaction between the process steps. It can help to identify potential control points [12].

In this way the Flowchart is a tool that helps individuals to have a precise notion of the entire process, properly structured and that is easy to visualize. In these charts are illustrated the set of tasks, variables, inputs and outputs that are the basis of the elaboration of a product. "The descriptions that define the process should enable its understanding and provide the basis for any critical examination necessary for the development of improvements. It is essential the process descriptions to be precise, clear, and concise. " [16].

Fig. 3 illustrates a flowchart and some of the forms used in its construction and the meaning.

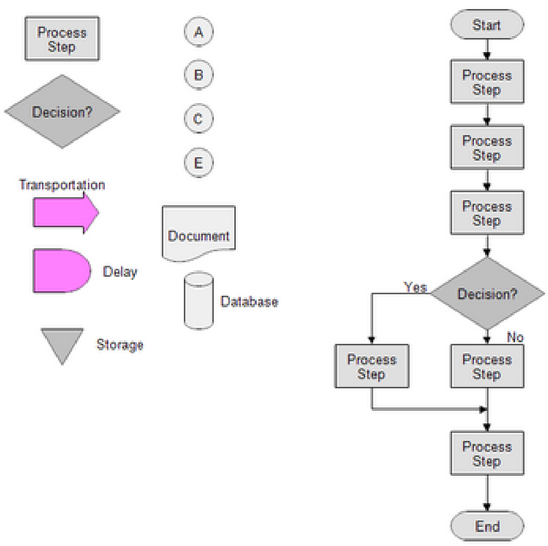


Fig. 3 – Flowchart example [15].

2.5 Histograms

The histogram is one of the quality statistical tools and it is used to graphically represent a large amount of numerical data (see an example in Fig. 4).

Analyzing the histogram, it is possible to identify longer-occurring data ranges and interpret this information easily and simpler than following a large table or a report with only numbers and/or values [17]. The Histogram is a bar graph used to represent the variation of a set of data grouped into contiguous classes. It aims is to quickly identify the patterns of variability inherent in a given process depending on the form of its distribution, in order to investigate the possible determinants.

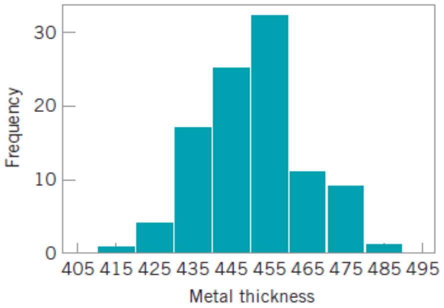


Fig. 4 – Histogram example [12].

2.6 Scatter plots

Scatter plots are very useful in identifying a potential relationship between two variables. The data are collected in pairs of coordinates (yi, xi), for i = 1, 2, ..., N. The shape of the scatter diagram usually indicates which type of relationship can exist between the two variables [12].
In other words, the scatter diagram shows what happens to the values of a (dependent) variable Y when the values of a (independent) variable X increases. A practical example of what has been said is when it is intended to evaluate whether there is a relationship between the increase in the number of defects with the increase in the extrusion temperature.
As can be seen from the analysis of Fig. 5, the set of points in the scatter diagram reveals whether or not there is a strong or weak, positive or negative correlation between the variables [16]. In the two scatter plots in the left, we observe a linear correlation between the variables. In the first case positive, and negative in the second. The last (in the right) scatter plot do not indicates the existence of any correlation between the variables.

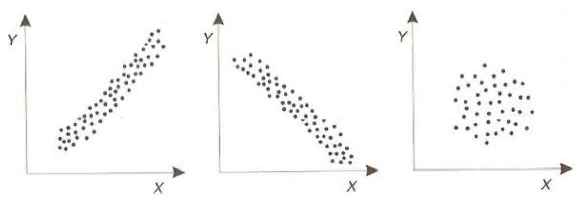
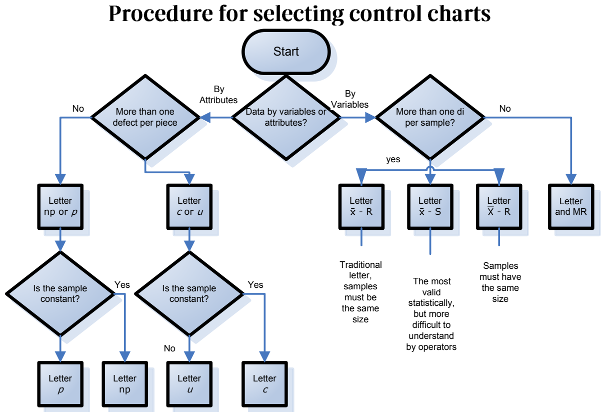


Fig. 5 – Types of correlation [18].

2.7 Control charts

A control chart or control chart is a graphical representation of a quality characteristic that is recorded over certain time intervals [19].
The graph shows information of the mean value of the process ($\overline{X}$), represented by a center line and two other reference lines, respectively representing the Upper Control Limit (LSC) and Lower Control Limit (LIC).
To assume that a process is under statistical control, all samples must be included in the zone defined by the limits [19]. If one or more points are outside the range, the process is said to be out of control. However, there are exceptions even when the process is controlled. These situations are identified when the points present a systematic and not random behavior. In this case it is considered that there should be a special cause for the occurrence. When a special cause is detected, the reason for its existence must be ascertained and corrective actions must be taken.
Control charts can be divided into two main categories: control charts by attributes and control charts by variables. The first are charts that represent data of the qualitative type, which are expressed in terms of good or bad, accept or reject. To analyses the data by attributes, there are *p* charts, *np* charts, *c* charts and *u* charts. The second are those that represent data of the quantitative type, such as the dimensions of a product. For quantitative variable data, the charts commonly used are control charts of mean $\overline{X}$, charts of amplitude R and charts for individual values.

Procedure for selecting control charts



Variables	Attributes
Mean and amplitude Chart $\bar{x}$ and Chart *R*	Proportion of nonconforming unit Chart *p*
Mean and Standard Deviation	Number of nonconforming units Chart *np*

Chart $\bar{x}$ and Chart *S*	
Median and Amplitude Chart $\tilde{x}$ and Chart *R*	Number of defects Chart *C*
Individual observations and Moving Amplitudes Charts *X* e Charts *MR*	MR Number of defects per unit Chart *u*

Fig. 1 – Types of control charts and selection process (Adapted from [13])

Although there are more types of control charts, these are the simplest and most used ones, and the selection of the control charts most appropriate for each situation can be driven by the scheme presented in Fig. 6.

2.7.1 Control charts by variables

According to the features and data to be worked on, different control charts may be applied. Next, will be identified the types of charts by variables and also the sequence for their construction, according with [12].

Charts of mean $\bar{X}$ and amplitude R

The chart $\bar{X}$ is used to control continuous type variables (physical measurements, for example), assuming that the quality characteristic follows a normal distribution with mean μ and standard deviation σ.

Since in practice the parameters μ and σ are not known, then available estimates $\bar{X}$ and *S*, using formulas (1) and (2), should be used

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (1) \text{ and}$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2} \quad (2)$$

where,

$\bar{X}$ = Mean sample;

S = Standard deviation sample;

X_i = i-th element of the sample *i* with *i=1, 2, 3, …n*;

n = number of elements or sample size.

Knowing that $\bar{X}$ it is normally distributed, with mean μ and standard deviation $\sigma_x = \frac{\sigma}{\sqrt{n}}$. If Z defined as: $Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}}$

Z follows a standard distribution with mean 0 and standard deviation 1, i.e., $Z \sim N(0,1)$.

As the process analysis is performed by sampling, the estimation of the mean and the variability of the process is performed through an interval structure, which provides an interval in which the true mean and population variability are assumed.

Since we do not know for sure where the true population parameter is, a probabilistic assignment of the interval at which the true value might be, should be used.

This interval is called the confidence interval, and the associated confidence is 1 - α, where α is the probability of error. A confidence interval of 100 (1 - α)% is established from two limits, and the probability of the true value of the parameter being included within the interval is 100 (1 - α)% [20].

In the SPC, 99.73% confidence intervals are usually used. For example, to construct a confidence interval of 99.73% for the mean, we can calculate the limits L (lower) and U (upper), such that:

$$P\{L \leq \mu \leq U\} = 99{,}73\%$$

The confidence limits of 100 (1 - α)% are calculated using the normal distribution.

$$\bar{X} - Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \leq \mu \leq \bar{X} + Z_{1-\alpha/2}\frac{\sigma}{\sqrt{n}}$$

where $Z_{\alpha/2}$ represents the quantile of the standardized normal distribution corresponding to the probability of the error $\alpha/2$.

For confidence intervals of 99.73% we have:

$$\bar{X} - 3\frac{\sigma}{\sqrt{n}} \leq \mu \leq \bar{X} + 3\frac{\sigma}{\sqrt{n}}$$

The limits of the confidence interval can be considered as limits of the control chart $\bar{X}$. Then the limits of the control chart $\bar{X}$ are:

$$LSC = \bar{X} - Z_{1-\alpha/2}\frac{\sigma}{\sqrt{n}} \quad \text{e} \quad LIC = \bar{X} - Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

Generally, it is used 3σ (three standard deviations) for the $Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$ value. In that case, the central line and the control limits of this chart are:

$$LSC = \bar{X} + 3\sigma \quad (3)$$

$$LC = \bar{X} \quad (4) \text{ and}$$

$$LSC = \bar{X} - 3\sigma \quad (5)$$

To calculate the control limits, and considering the existence of multiple samples, the amplitude is calculated initially (R = max X_i - min X_i) and the mean $\bar{X}$ for each sample, and then the mean amplitudes and the mean sample means are calculated as follows:

$$\bar{C} = \frac{R_1 + R_2 + \ldots + R_n}{n}$$

$$\bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \ldots + \bar{X}_n}{n}$$

Therefore, the variability is estimated using the mean amplitudes within each sample to ensure that it is associated only with the common causes. Thus, it is not correct to estimate the variance using the

standard formula of standard deviation (S) applied on the set of all the data, because in this way the variance estimate could be associated with common causes (within samples) and special causes (between samples).
Once having calculated $\bar{X}$ and R, the control limits of the means are calculated considering the extension of six standard deviations of the means (three for each side), which according to the Normal distribution comprises 99.73% of the sample mean values.
Formulas (3) and (5) can be represented only by:

$$CL = \bar{\bar{X}} \pm 3\sigma_{\bar{X}},$$

where the formula with the sign "-" is equivalent to formula (3) and with the sign "+" is equivalent to formula (5), being:

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}}$$

Replacing this expression in the previous equation results in:

$$CL = \bar{\bar{X}} \pm 3\frac{\sigma}{\sqrt{n}},$$

where the variability of the individual values is estimated from the mean of the subgroup amplitudes, using the estimate:

$$\sigma = \frac{\bar{R}}{d_z},$$

where d_2 is a constant that depends on the size of the sample, whose3 values are in Table 6.

Table 6 – Values of constants D_4, D_3, d_2, A_2 used in the construction of control charts

n	2	3	4	5	6	7	8	9	10	15	20
D_4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78	1.65	1.59
D_3	0	0	0	0	0	0.08	0.14	0.18	0.22	0.35	0.42
d_2	1.13	1.69	2.06	2.33	2.53	2.70	2.85	2.97	3.08	3.47	3.74
A_2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31	0.22	0.18

Replacing this expression in the previous equation yields:

$$CL = \bar{\bar{X}} \pm 3\frac{\bar{R}}{\sqrt{n}d_2}$$

and being it is obtained the control limits for the means:

$$CL = \bar{\bar{X}} \pm A_2\bar{R} \qquad (6)$$

where A_2 is a constant that depends on the sample size, whose values are shown in Table 6.
The control limits for the amplitudes are calculated as follows:

$$CL_R = \bar{R} \pm 3\sigma_R \qquad (7)$$

where:

$$\sigma_R = d_3\sigma = d_3\frac{\bar{R}}{d_2}.$$

Replacing this expression into equation (7), it is obtained:

$$CL_R = \bar{R} \pm 3d_3\frac{\bar{R}}{d_2} \qquad (8)$$

Considering $D_4 = 1 + 3\frac{d_3}{d_2}$ e $D_4 = 1 - 3\frac{d_3}{d_2}$ in equation (8), it is obtained the control limits for the amplitudes:

$$LSC_R = D_4\bar{R}$$
$$LIC_R = D_3\bar{R}$$

Where D_4 and D_3 are constants that depend on the sample size, whose values are presented in Table 6.

2.7.2 Process capacity

The purpose of the capacity calculation is to determine whether the process is capable of producing products within the specification tolerances. To study the capacity of the process it is necessary to know the specifications [21].
Producing according to these specifications is the main focus of the study of process capability and also a guarantee of process and product quality of any company. Specification limits (upper – LSE and lower – LIE) are the areas on either side of the centerline, or mean, of data plotted on a control chart that meets customer requirements for a product or service. This area may be larger or smaller than the area defined by the control limits. If a process undergoes centralization changes and/or an increase in process dispersion, it may yield production outside the specification limits.
Capacity process studies are followed by the application of control charts and their realization depends on the positive validation that the process is under statistical control.
These studies result in process capability indices, which are numerical measures that relate aspects inherent to the fulfilment of specification limits.
Many process capability indices can be applied, such as C_p e C_{pk} [22].
The calculation of the capability index C_p can be done by the following formula:

$$C_p = \frac{LSE - LIE}{6\sigma}$$

where: σ – process standard deviation;
LSE – Specific upper limit;
LIE – Specific lower limit.

The capacity of the process is then characterized taking into account the value obtained for the index C_p, as described in the Table 7.

Table 7 – Reference values for classification of the process by índex C_p

Capacity Index Value	Process
< 1	Unable
1 a 1.33	Acceptable
> 1.33	Able

However, C_p does not take into account the centrality of the process, for instance, it does not take into account the position of the mean relatively to the specification limits. For this reason, should be considered the Capacity Index C_{pk} that is given by:

$$C_{pk} = \min((C_{pk})_I, (C_{pk})_S),$$

where $C_{pk} = \frac{\mu - LIE}{3\sigma}$ and $(C_{pk})_S = \frac{LSE - \mu}{3\sigma}$

Some observation can be made regarding the indexes C_p e C_{pk} [12] (also illustrated in Figure 17):

- Index C_{pk}, which measures the actual capacity of the process, is always less than or equal to the C_p index, which measures the maximum capacity of the process when it is centred;
- Index C_{pk}, is less than index C_p when the process is off centre and is equal to C_p when the process is centred;
- The $C_{pk} > 1$ is necessary for the customer specification to contemplate 6 σ - 99.73% of the products produced and that the defective fraction is 0.27%.

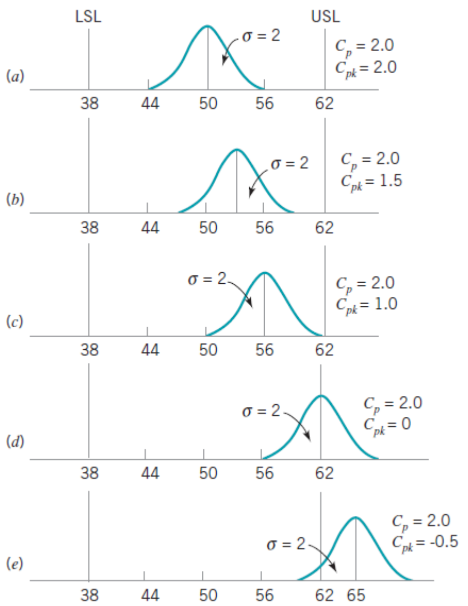


Fig. 7 – Relationship between C_p e C_{pk} [12].

3 The Usage of Quality Tools in the Company ADLA, S.A.

The commitment to programs directed to improve the quality of processes is increasingly an attitude to adopt, in order to face the current time strong competition in all sectors and markets. It is necessary to move towards optimized manufacturing processes to increase competitiveness, reduce scrap/nonconformities and maximize profits.

3.1. The company

ADLA Aluminium Extrusion S. A., is a young company (constituted in 2011) dedicated and specialized in the development and production of aluminium profiles. It is a national company, which manufactures aluminium profiles, whose application includes engineering, architecture and industry works in general. Inserted in a demanding market, its main pillars are quality (ISO 9001: 2008 certified company since 2013), innovation, technology and environment (company certified according to ISO 14001: 2008 since 2016).

This company appears as the productive link and exporter of the business group to which it belongs, integrating, in view of the existing situation, the productive part and the international side. In this sense, ADLA has as its mission:

"To provide, for the global market, innovative, differentiated and high-quality products in the field of aluminium extrusion, having as guiding principle the continuous improvement of its reality."

3.2. Data collection and Methodology

In order to carry out this study we used the analysis of several data sources, namely, company documents and fact sheets. In an initial phase, an evaluation of the types of nonconformities with higher occurrence was carried out, through a data collection with eight months of production (data presented summary in table 8).

Next, a diagnosis was made, trying to observe possible variations of the extrusion parameters during the last productions. After analyzing the results, a set of measurements/changes (to be carried out in future extrusions) will be implemented. Some extrusion conditions are crucial, namely extrusion speed, container temperature, bead length and bead heating temperature, which the experiment "points" indicates that they allow to optimize the process, reducing the number of nonconformity and consequently the percentage of scrap from each extrusion/production. These assumptions are verified in the previous paper, where the available data about extrusion parameters are studied, as well as, the relationship between them and their impact on the quantity of scrap produced.

In support of this whole process, a theoretical framework was used resorting to a literature review on the key concepts addressed, that is, a theoretical development of the aluminium extrusion process, Statistical Process Control and other quality tools.
According to the different stages of this study, multiple quality tools were used. The flowchart to represent the production process, the Pareto diagram to identify the major cause of defect rejection (nonconformities), the Ishikawa diagram to identify and structure the possible causes that give rise to the various defects, among others.

3.3. Description of the productive process of extrusion

The production process in the Company ADLA Aluminium Extrusion S. A. starts in the sales department where the orders are received, separated and confirmed. It is in this moment that the entire production plan is built, based on the installed capacity. The process is basically divided into four parts: aluminium extrusion, stretching, cutting and heat treatment combined by small processes. In order to show all phases of the process, as mentioned before, a flow chart can be used, and in Fig. 8 is presented the Aluminium Extrusion Flowchart of the company ADLA, S.A.

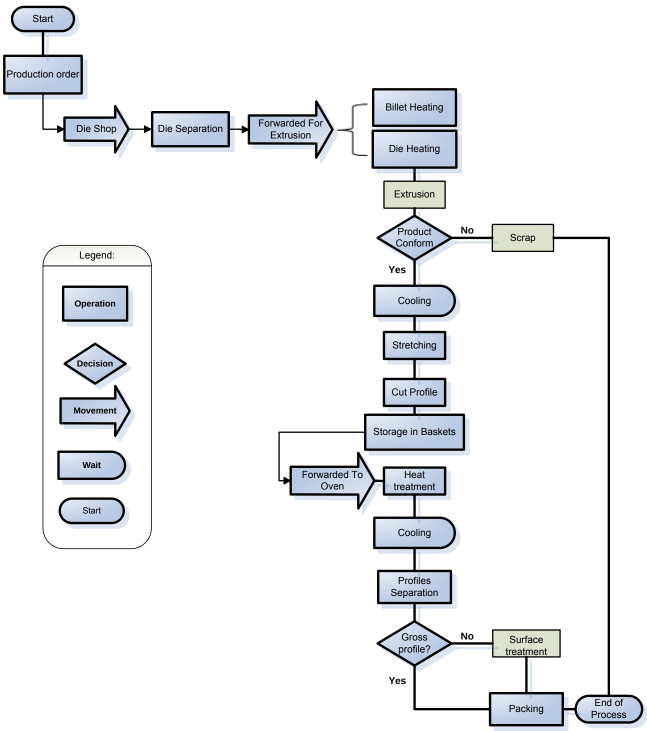


Fig. 8 – Aluminium Extrusion Flowchart of ADLA, S.A.

Aluminium extrusion is a process in which a press forces a cylindrical aluminium billet against a die, forming products of constant section. In ADLA Aluminium Extrusion S. A., aluminium billets are stored in batches according to the alloy and the supplier from which the raw material came (Fig. 9). There is a first visual, dimensional quality check and confirmation of the quality certificates that come with the billets. When a batch is selected for extruding, the billets are transported to the feed ramps (Fig. 10) and the process starts with a simple cleaning of the surface, to remove dirt and some surface impurities that may exist (Fig. 11).


Fig. 9 – Raw material


Fig. 10 – Feeding Ramp


Fig. 11 – Aluminium brushing/cleaning

After being cleaned, the billets enter the preheating furnace (Fig. 12) where they are heated in a most homogeneous way. This gas-fired oven consists of five heating zones allowing gradual heating and avoiding that the billet is exposed to high temperatures for an extended period of time, and, on the other hand, to thermal gradients (temperature differences throughout the billet).
After the production planning, the production system starts the extrusion process of the profiles. The extrusion is prepared by heating the billet according to the specified alloy and the dies already prepared. At the exit from the oven the billets are cut (Fig. 13) and transported (Fig. 14) to the press container which remains heated to a constant temperature. Then the billet is extruded. Prior to extrusion the die is also heated to prevent thermal shocks.


Fig. 12 – Heating Oven


Fig. 13 – Cutting Billet


Fig. 14 – Billet Transporter

At the exit of the die the profiles can be cooled down by air or water, depending on the alloy and the profile. Normally the profile is pulled by a puller, which guarantees a constant output speed in order to ensure a regular product.
When coming out the press the profiles are inspected visually, the production control register is completed and if they meet the specifications the

production order continues. Otherwise, they are rejected, the nonconformity is recorded and forwarded to the quality department.
In the same production series, the profiles are extruded continuously, being cut with hot saw (Fig. 15) to each billet that is pressed. This cut is precisely made from the area where a billet joins the previous one. The profile, already cut, is attached at both ends and is stretched (Fig. 16), so that it is straight and without curvatures. The zones next to the splicing of the billets are eliminated (scrap), since they are zones of great heterogeneity. After passing in the stretcher (Fig. 17), the bars are cut (Fig. 14) into bars of lower length and placed in containers (Fig. 18) which are transported to the aging furnaces (Fig.19), if the profiles are aged, or for shipment.


Fig. 15 – Hot Saw


Fig. 16 – Stretcher


Fig. 17 – Final Saw


Fig. 18 – Containers


Fig. 19 – Aging furnaces

The profiles, after aging, can also undergo an anodizing or lacquering surface treatment, according to the customer's requirements. The initial conditions of the billet are crucial for good extrudability and for a final product with the desired properties and qualities, from mechanical properties, to response to subsequent heat treatments and surface treatments, to surface quality and adhesion of paints or coatings

3.4. Description of nonconformities in the extrusion production process

From the data collection and the direct observations of the extrusion process, several situations were recorded that contribute to the occurrence of nonconformities (NC). In the phases of the extrusion process there are several criteria that must be respected, namely in terms of their production order specifications and process conditions. These criteria are often neglected by operators, which entails a series of failures that run along the process.

It commonly occurs that only when the product gets to the end of the production line it is when the NC in these products are verified, which is problematic both financially and for the fulfilment of deadlines. According to the production manager, the main point in the extrusion preparation stage is the lack of temperature control.
The execution of this control is of fundamental importance because if the temperature of the billet and the tool (matrix) does not reach approximately 460°C the quality of the product will be affected. It also stresses the importance of checking the conditions of use of the machine, before starting the process, in order to avoid failures that can be easily prevented by preventive maintenance, such as: air retention in the press, excessive lubrication in the pressure discs, and leakage. This lack of temperature control and machine maintenance may be responsible for the appearance of bubbles in the profiles (one of the most common defect types in the ADLA Aluminium Extrusion S. A. extrusion process).

Table 1 – Checklist for the types of NC observed in ADLA, S.A.

Type of defects	Total	Accumulated value (€)	Accumulated %
Blisters	15116.76	15116.76	37.69
Scratches/Damages	13906.55	29023.31	72.36
Out of Angle	2786.85	31810.16	79.31
Lines	2429.72	34239.88	85.37
Wrinkle	2422.77	36662.65	91.41
Hole B.	1253.19	37915.84	94.53
Concavity	804.09	38719.92	96.54
Rough Surf	665.41	39385.34	98.19
Twist/Bends	551.42	39936.76	99.57
Convexity	172.80	40109.56	100.00
Total	40109.56		

In the process of stretching (traction of the profiles), inspection of the measurements and the use of the squares are often neglected by the operators, leading to the occurrence of dimensional errors and the products out of miter. During the direct observation of the process it was identified that the cutting stage is one of the most important in the quality control of this process, because it is at this stage that measurement errors usually occur, causing the wrong cutting and the surplus in excess of ends. These wrongly cut products/profiles are sent to scrap because they are out of standard size and cannot be reused.
Another very important factor for the creation of scrap is the accommodation of the profiles in the transport baskets, in which the criterion of

packaging according to the dimensions of these products must be respected. The accommodation of heavy profiles on the lighter profiles results in a direct kneading of the profiles. Based on the reports of NC obtained in the company, it was possible to identify ten NC and then determine the frequency of occurrence, as well as the percentage and significance in kilograms of nonconforming product of each one, in the period of time analyzed.

3.5. Data analysis through quality tools

3.5.1 Main Nonconformities and Causes

Based on the information extracted from the Check Sheet the Pareto Diagram (Fig. 20) was made for the higher frequencies of NC. The diagram orders the frequency of occurrences of a particular characteristic to be measured, from highest to lowest, and provides the information in a way that allows the concentration of efforts for improvement in areas where the greatest gains can be obtained. Thus, the "Bubbles" defect, which represents 38% of the NC, is the most representative failure found during the process.

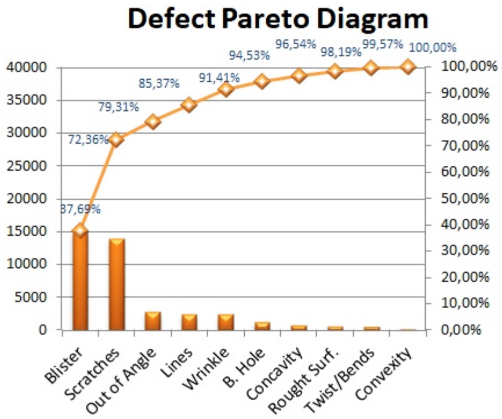


Fig. 20– Pareto diagram for NC in ADLA, S.A.

Based on the classification of the bubbles, as the most significant and recurrent non-conformity in the process, together with the person in charge of production, press workers and quality control, a brainstorming was done to elaborate the Ishikawa Diagram or Cause and Effect Diagram to explore the causes of non-compliance. The resulting diagram is shown in Fig.21.

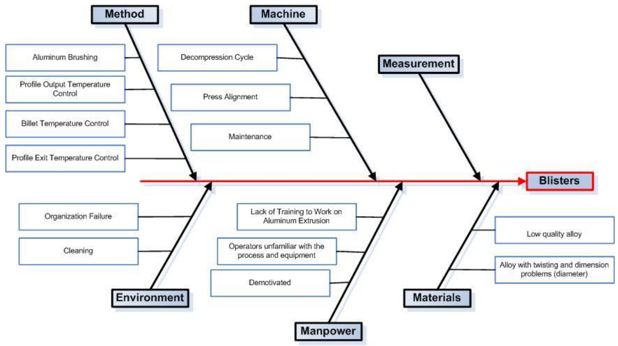


Fig. 20 – Cause and Effect Diagram NC "Blisters"

In the course of the brainstorming, the team members assigned values on a scale of 1 to 5 for the causes raised (representing 1 = very shocking cause and 5 = negligible cause) so that it was still possible to identify, among the causes mentioned, which were the most significant ones were bubbles, and the results presented in Table 10 were obtained. The levels of this scale are described in Table 9.

Table 9 – Rating scale of the causes for NC "Bubbles/Blisters"

Rating Scale				
Very Important	Important	Significant	Little Important	Insignificant Important
1	2	3	4	5

Table 10 – Classification of the causes for NC "Bubbles/Blisters

Method	Evaluation	Machine	Evaluation
Time at maximum	1	Decompression cycle	1
Aluminium Brushing	3	Press Alignment	2
Temperature control at profile output	2	Maintenance	3
Billet temperature control	2	Lack of Lubrication	3
Container temperature control	1		
Average	1.80	Average	2.50
Environment		**Manpower**	
Lack of organization	3	Untrained workers aluminium extrusion	2
Cleaning	4	Poorly motivated staff familiarized with the process and Machinery	4
		Low Technical Level	2
Average	3.50	Average	2.67
Measure		**Material**	
Without temperature sensors calibration	5	Low quality alloy	1
		Billets with problems	3
Average	5.00	Average	2.00

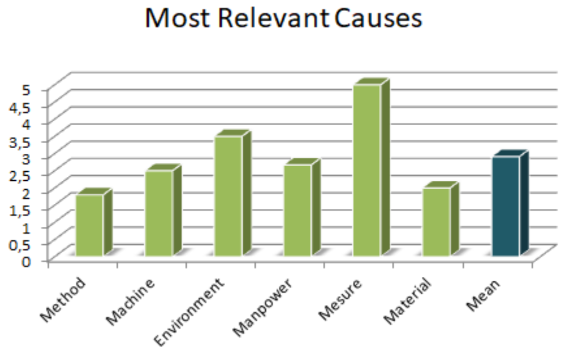


Fig. 22– Causes of the NC "Bubbles"

Based on the data collected, we created the graph in Fig. 32. From the chart, it can be observed that the causes related to the method were those evaluated with greater impact for the occurrence of NC under study. This analysis reinforces what was observed during the data collection, by means of the direct observation of the extrusion of the profiles. Thus, it will be essential to control temperatures as well as the maximum pressure time, which as can be seen in Table 10 are the most scored causes.

3.5.2 Extrusion variables that most affect the appearance of the "Bubble" defect

During the extrusion process there are several variables that directly affect the quality of the extruded profiles. After analyzing the causes that most affect the appearance of the "Bubble" defect, the target variables of study/control are: The time at the maximum extrusion pressure and the temperature of the container - as can be seen in Table 10 are the most relevant causes. Thus, these variables were monitored using control charts. Before that, a brief description of each is given.

After analyzing the extrusion process, and selecting the target study variables to be controlled the control limits and the mean for each sample were calculated. Once the appropriate samples for the correct implementation of the control charts were collected. The control charts of the mean ($\bar{X}$) and Amplitude (R) were considered. These charts allow having a perspective of the variability of the samples over time. Thus, we can say whether the process is controlled or not.

3.5.2.1 Time at maximum pressure

The time at maximum pressure can be defined as the time at which the hydraulic pressure remains at its maximum value [23]. It also underlines that during the extrusion cycle, and after the billet is inside the container and after the press touches the billet, the hydraulic pressure should reach a value of approximately 211 Bar and remain at this pressure for 4 to 8 seconds. This gives time for the billet deformation inside the container, thus giving rise to the plastic deformation of the metal.

Fig. 23 shows a graph, typical for aluminium alloys, where it is possible to observe the extrusion pressure as a function of the piston movement. In the graph could identifies six main stages that occur during the extrusion of a billet [24]. Region A shows that the load in extrusion initially increases very rapidly as the billet upsets to fit the container. There is a further increase in pressure (region B) until the extrusion begins. In this process, the structure is heterogeneous with progressively increasing dislocation and sub grain density mainly concentrated in the die region. In C, peak pressure region, a peak appears because a greater dislocation density is required to reach steady state extrusion than is required to maintain it. After the peak pressure has been reached, the extrusion pressure falls as the billet length decreases. In the extrusion, the process is characterized by the absence of friction between the billet surface and the container. The macrostructural and microstructural changes are complex and contain second phases, which include precipitates and solutes that hinder dislocation movement.

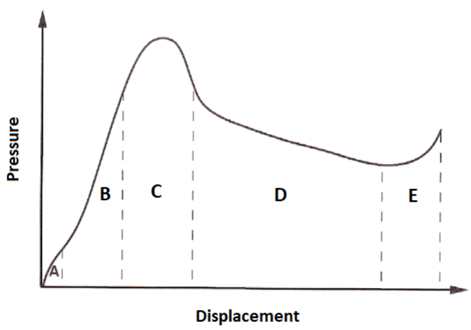


Fig. 23 – Extrusion pressure chart [26].

Analyzing the control charts means and amplitudes, through Fig. 24 and Fig. 25, it is possible to observe that, for the variable under study (time in the maximum pressure), the process does not present an adequate statistical behavior. It can be inferred that the process is out of statistical control, indicating the presence of special causes of variation. Evidence for this assertion is easily seen in Fig. 25, where it can be seen that there are points outside the control limits.

Fig. 24 – Average Chart ($\bar{X}$) - Time at Maximum Pressure

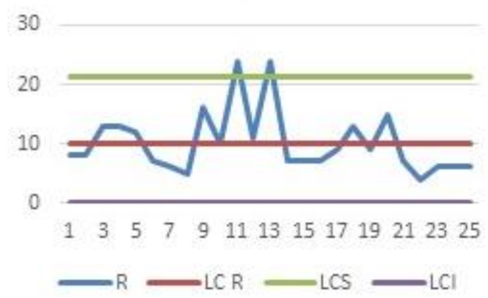


Fig. 25 – Amplitude Chart (R) – Time at Maximum Pressure

3.5.2.2 Container Temperature

The ever-increasing pressure for higher productivity and recovery at the extrusion press demands better tooling and knowledge of tooling system providers. Containers (illustrated in Fig. 19) are probably the most misunderstood press tooling. A container does more than just contain billets at high pressure and high temperature during extrusion. They affect surface, shape, and dimensions of the profile and also the life of the dummy block, liner, mantle and container housing, and the energy bill. Most importantly, the goal for the container is to have temperature stability of the liner, not temperature uniformity of the mantle [25].

During extrusion, there is a tremendous amount of heat generated in the container, from the contact between the heated billet and the container, which causes a thermal exchange between them. It is then necessary to heat and control the temperature of the container in order to minimize this exchange. The temperature of the container should be in a range between 20 and 50ºC lower than the temperature of the billet. This temperature, in spite of allowing a small thermal exchange, increases the friction between the billet and the container, causing the impurities and oxides of the billet surface to be retained in the bead (process discard) at the end of the extrusion. The heat generated depends on the various variables, such as the billet length, the billet temperature, type of alloy, speed of extrusion and extrusion ratio [23].

Next, we present the control charts (charts of average temperatures and temperature amplitudes) referring to the temperature of the container.

Fig. 26 – Average chart (R) – Container temperature

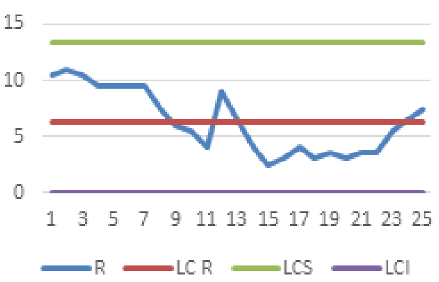


Fig. 27 – Amplitude chart (R) – Container temperature

From the analysis of the Fig. 26 and Fig. 27 it will be seen that in general the values are within the control limits.

4 Conclusion

This work had as main goal the usage and implementation of quality tools, in particular statistical control of processes tools, in order to reduce the variability of the process and in this way to reduce the amount of scrap produced. An analysis and examination of the main defects that may arise due to poor use of extrusion parameters, was also performed. This challenge assumes a high level of motivated demand, fundamentally for quality standards and the need for a decrease in manufacturing costs and an increase in productivity. During the process control, routinely collected data are used and this information is available in a practical way, so that all the employees involved can improve the process. With this idea in mind, it is extremely important to develop a new culture in the company that allows the motivation and cooperation of all in the search for continuous improvement of the whole process. Therefore, the SPC effect will have a great impact on quality and productivity indicators, adding many gains to the organization, effectively reflecting the company's objectives. So the cost of implementing these improvements in quality and productivity is almost insignificant, but the profits can be huge. In the course of this work, a plan was defined that aimed to determine the main defects detected during the extrusion process and the study of possible causes. Thus, it was concluded from the examination of the critical defects recorded during the extrusion process that the defects in the blisters represented around 38% of the defects recorded in the productions of the period under analysis. In order to find a response to the high percentage of this defect, a cause and effect diagram was developed to represent the relationship between an effect and all possible causes that may be contributing to this defect. This type of tool, together with the brainstorming sessions take possible to indicate corrective actions.

From proposed actions, Time at the maximum pressure and Container Temperature control charts are presented. During the execution of these charts, there were points outside the control limits, with respect to the variable "Time at Maximum Pressure" justifying the need of intervention.

In order to minimize the possibility of points outside the control limits, it is necessary to periodically train the employees in order to raise awareness of the consequences of not having a systemic visualization of this type of data. To have greater and better control over the temperatures and times of these two variables, a recording and monitoring system that is coupled to the extrusion press is suggested and that automatically creates an alert whenever the specification limits are exceeded. This is a highly recommended measure, because through it the operator can read the results in a simple and intuitive way.

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