

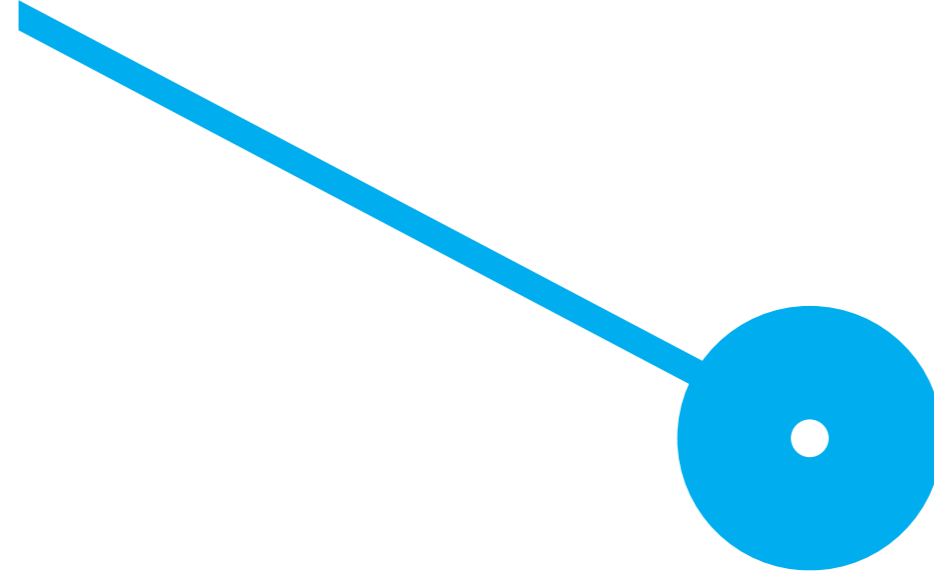
**Scrap Optimization in an Aluminium
Extrusion Industry**
Nuno Miguel Alves Carvalho

11/2017

Nuno Miguel Alves Carvalho. Scrap Optimization in an aluminium extrusion
industry

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It is time to end this chapter of my life by finishing this project/dissertation. Two years ago, I started the journey with aspirations and expectations, wondering what it would be like two years after. Now I can see it. It is a moment filled with joy of my achievements, and more importantly, with more knowledge and more certain about the future.

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The last, but not least to my wife, for the great patience she has with me especially during this work, and above all to my daughter for all she means to me.

Abstract

The goal of this study is to propose a set of improvements that allow increasing the productivity and quality of the product commercialised by the company ADLA Aluminium Extrusion S. A. Namely, it is intended to reduce the percentage of scrap during the aluminium extrusion process. This process depends on a set of parameters such as the length and temperature of the billet, the extrusion speed, the extrusion ratio and the profiles temperature, among others. These parameters determine the quality of the product as well as the amount of scrap produced. In the bibliographic research it was very evident a strong relationship of dependency between the different variables being studied. Thus, and through the study here being developed, it is intended to obtain indicators for scrap optimization, so that in the future it is possible to settle which extrusion variables allow better results. In a first stage (paper) it is presented a brief introduction to the theme, the variables that influence the process are identified and the guidelines for the data collection are defined. After that, it is intended to find out in which way the variables influence the scrap production, using statistical techniques, in particular, a multivariate linear regression, which will allow us to identify the level of importance of each variable being studied for scrap production. In a second phase (paper) and starting from the principle that there is a direct relationship between the extrusion parameters and the defects, an analysis was made of the amount of scrap produced and the types of defects with the greatest impact. Thus, the present work aims to improve the quality of a process using Statistical Process Control techniques, as well as to foment continuous improvement practices.

Keywords: Extrusion, Aluminium, Optimization, Multivariate Linear Regression, Statistical Process Control, Quality Control.

Resumo

O presente trabalho, tem como objetivo propor um conjunto de melhorias que permitam aumentar a produtividade e qualidade do produto comercializado pela empresa ADLA, Extrusão de Alumínio, SA. Por outro lado, pretende reduzir-se a percentagem de sucata produzida durante o processo de extrusão de alumínio. Este processo é influenciado por um conjunto de parâmetros tais como: comprimento e temperatura do bilete, velocidade de extrusão, rácio de extrusão e temperatura dos perfis, entre outros. Estes parâmetros determinam a qualidade do produto e a quantidade de sucata produzida. Da pesquisa bibliográfica, foi evidente uma forte relação de dependência entre as diferentes variáveis em estudo. Assim, e através do estudo desenvolvido, pretendeu obter-se indicadores para os quais as variáveis de extrusão permitam obter melhores resultados, ou seja, diminuir a percentagem de sucata produzida. Numa primeira fase apresenta-se, então, uma breve introdução ao tema, identificam-se possíveis variáveis que influenciam o processo e definem-se as linhas de atuação para a recolha dos dados. Posteriormente, pretendeu-se averiguar de que modo as variáveis influenciam a produção de sucata, fundamentais para a empresa, utilizando técnicas estatísticas, em particular uma regressão linear múltipla, que permitiu identificar o nível de significância das variáveis em estudo. Numa segunda fase e, partindo do princípio que existe uma relação direta entre os parâmetros de extrusão e os defeitos, foi efetuada, com o auxílio das ferramentas da qualidade, uma análise à quantidade de sucata produzida e a quais os tipos de defeitos com maior impacto. Assim, o presente trabalho visa melhorar a qualidade de um processo através do uso do Controlo Estatístico do Processo, bem como fomentar práticas de melhoria contínua.

Palavras-chave: Extrusão, Alumínio, Otimização, Regressão Linear Múltipla, Controlo Estatístico do Processo, Controlo da Qualidade.

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Acronyms

QM – Quality Management

MS – Magnificent Seven

PC – Process Control

SPC – Statistical Process Control

UCL – Upper Control Limit

LCL – Lower Control Limit

USL – Upper Specification Limit

LSL – Lower Specification Limit

NC – Nonconformities

1. INTRODUCTION

1.1. THEORETICAL FRAMEWORK

Extrusion is one of the major metal forming processes. This procedure is used to transform an ingot in to a useful product, with the size and shape required. Extrusion is a flexible manufacturing process, where a single extrusion press is used for multiple materials and can produce infinite number of shapes changing the die and the tooling associated with it. Aluminium is the most widely used metal for extrusion process because of its considerable strength and ductility. Over the last years, the field of metal forming is characterized by a dynamic development. There are several reasons for this, but one of the most significant is the use of computers and powerful software, which radically changed the approach and the way of process design and planning (Hosseini, 2012). At present, in ADLA Aluminium Extrusion S. A., the extrusion process parameters are almost selected based on experience. Extrusion is a very complicated process, which requires proper process parameters to be used to get optimum settings to produce a quality product. Consequently, optimization of process parameters for aluminium extrusion has gained significant importance. Therefore, most of the researchers, such as, Zhang, Qamar and Bashir have dedicated their studies towards the optimum selection of parameters, having in view of the best quality product (Chahare & Inamdar, 2017).

In order to obtain the adequate characteristics of the extruded aluminium it is necessary take into account the extrusion variables. The metal flow is influenced by several factors, such as: temperature of billet, temperature of container, extrusion pressure, velocity of extrusion, size of billet (length and diameter) and extrusion ratio, among others. Otherwise, variables such as temperature, length of the billet, press speed, profile geometry and profile outlet temperature, among others, were considered in Almeida et al. (2017). All of the variables described

above are related with possible defects during the extrusion that lead to production losses, either reflecting the cost of rework and/or the cost of scrap. Taking into account that extrusion variables play an extremely important role, concerning to the appearance of extrusion defects, it is important understand the origin of defects. It is also crucial to identify the influence of each variable on the appearance of a particular defect such as blisters, scratches, twists, concavity and convexity. Thus, this work aims to analyse, through a set of statistical tools, the entire extrusion process in order to reduce the amount of scrap produced.

1.2. OBJECTIVES

The present work has as main objective to obtain indicators that allow to optimize the fundamental parameters that occur during the process of aluminium extrusion, having in view the reduction of scrap produced. The process variables considered in this study involve the length and temperature of the billet, the extrusion speed, the extrusion ratio and the temperature of the profile (exit temperature). Studying the amount of scrap produced by variation of these variables, understanding their nature and establishing the relationship between them, is the first goal. It is expected that in the future, using this knowledge, the product quality can be improved.

Therefore, the main goal is to optimize the process. First, this work has the objective of implementing and analysing the variables of the aluminium extrusion process, as well as eliminate the causes that are in the origin of the quantity of defects produced in the company ADLA Aluminum Extrusion, SA. Then the application of some Statistical Process Control (SPC) tools are essential. This second phase aims to state causes or indicators which explain the variables behaviour and those that may have a more significant influence on the process. Is expected to find errors and opportunities for improvements in the process and reduction of defect causes, as a way to ensure a greater efficiency in the manufacture of aluminium profiles and, thus, to ensure a greater profitability in the productive process, minimizing the quantity of scrap produced.

1.3. STRUCTURE

This thesis is structured into three main sections, as presented in Figure 1. This first section includes the introduction, which provides an overview of the extrusion process and some literature related to this subject, then the objectives are detailed and lastly is presented this structure of the dissertation.

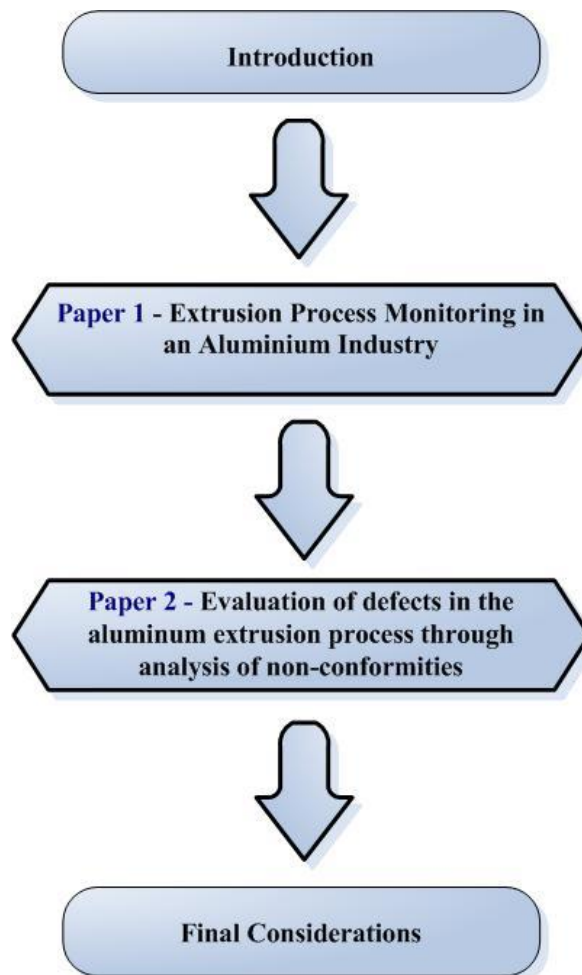


Figure 1 – Project Structure

The second section consists of two chapters corresponding to two papers/studies. First paper is dedicated to monitoring some extrusion parameters and studying their role to the scrap production. In the second paper an evaluation of the foremost defects, using statistical process control techniques is made.

The third, and last section, presents the conclusions and the contributions of this investigation to the theme.

2. EXTRUSION PROCESS MONITORING IN AN ALUMINIUM INDUSTRY

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Abstract

Nowadays the industrial competitiveness is a keyword in the survival capacity of firms. The metallurgical industry is not an exception neither their devoted to the extrusion process, in particular. Several parameters have influence in the aluminium extrusion process, such as the length and temperature of the billet, the ram velocity, the extrusion ratio and the profiles temperature. These parameters determine the quality of the product as well as the amount of scrap produced. In the bibliographic research, it was evident a strong relationship of dependency between the different variables being studied. This article's goal is to reduce the percentage of scrap during the aluminium extrusion process, studying which extrusion variables allow better results, increasing the productivity and the product quality of an aluminium industry, namely ADLA Aluminium Extrusion S. A. In the first stage, it is presented a brief introduction to the theme, the variables that influence the process are identified and the guidelines for the data collection are defined. After that, in order to find out indicators for minimization of the scrap production, statistical techniques, in particular ANOVA are used.

Key words: *Aluminium Extrusion, Extrusion Parameters, Product Quality, Optimization Process, ANOVA, Multivariate Linear Regression.*

1. Introduction

The extrusion, illustrated in Figure 2, is a technological process of plastic deformation where the material is submitted to high pressure by means of a punch; it is forced to pass through a cavity in the die in order to reduce/modify the shape of its cross-section (Saha, 2000).

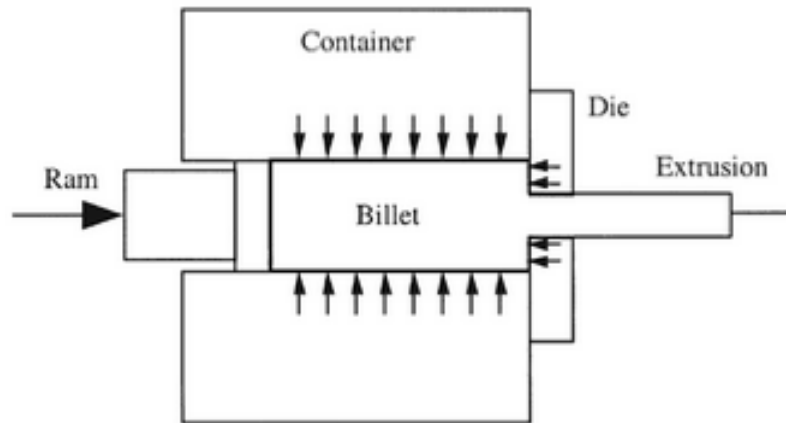


Figure 2 – Extrusion Process (Saha, 2000)

The extrusion technology allows to produce varied geometry components, which can be later applied in several areas (Shyamu et al, 2015, and Sreenivasulu and Srinivasa, Rao, 2016). This industrial process is used since the XIX century but the high use of extrusion technique occurred in World War II when different extruded aluminium profiles were used to produce aeronautical components (Abal, 2007). Throughout the time, aluminium alloys have been widely studied and developed. Nowadays, the extruded aluminium profiles can be found in different markets such as construction, transports, motor sports, industry and structures, due to their excellent mechanical properties.

On the other hand, and assuming that the commitment to programs to improve the quality of processes is increasingly a way to follow in order to face strong competition in all sectors and markets, it becomes necessarily fundamental the optimization of production processes, in pursuance of increasing the competitiveness, to reduce the wastes and maximize the profits.

In order to obtain the adequate characteristics of the extruded aluminium it is necessary take into account the extrusion variables. Thus, for the most demanding applications on the market is important predicting/controlling the properties of aluminium, if possible before, during and after extrusion. It allows collecting data to improve the extrusion process, both in terms of optimization of equipment and inherent variables.

In the investigation of Bajimaya et. al. (2007) the properties of the extruded aluminium shapes were affected greatly by the way in which the metal flows during extrusion. Since, the metal flow is influenced by several factors, such as: temperature of billet, temperature of container, extrusion pressure, velocity of extrusion, size of billet (length and diameter) and extrusion ratio. Otherwise, variables such as temperature, length of the billet, press speed, profile geometry and profile outlet temperature, among others, were considered in De Almeida et

al. (2017). Corroborating with this idea, Arif and Sheikh (2005) report that the quality of any extruded product (profile) is influenced by the chemical composition of the alloy, as well as the size and geometry of the profile, length and temperature of the billet and extrusion speed. In this way, it is essential to implement and apply a quality improvement program to the parameters of the extrusion process, based on the application of some statistical techniques. According to Montgomery (2009) the application of statistical methods in the production industry makes possible a more efficient use of raw material and manufacturing processes, affects the economy of production and makes possible the highest economic standards for goods produced and used by all. De Almeida *et al* (2016) used techniques of analysis of variance (MANOVA and ANOVA) to study the effects of processing conditions on polymer extrusion.

The main goal of this article is to obtain indicators that will allow to optimize the fundamental parameters during the aluminium extrusion process, focusing on the reducing of the scrap. Changing the experimental variables and checking the consequently response, is possible to understand their nature and the relationship between the process variables. Our final purpose is to produce improved products in the future in ADLA Aluminium Extrusion S. A. company.

In this sense, it was considered pertinent to implement a quality improvement program, having the following steps:

- Define which variables have the most impact on performance indices and the ones that are most critical to the process.
- Identify the causes of the high percentage of scrap and study possible corrective actions.
- Analyse extrusion parameters and identify those that most affect the final product.
- Implement some statistical process control techniques capable of monitoring the extrusion parameter.
- Prepare proposals and recommendations to stabilize the process and, on the other hand, increase productivity.

The length and temperature of the billet, the ram velocity, the extrusion ratio and the exit temperature of the profile are the variables process to have into account, in this study, because they are the actual available parameters in ADLA Aluminium Extrusion S. A. Company. To analyse the meaning of these parameters in the process statistical techniques are applied. The application of other statistical controlling tools of the process (CEP) can be considered in future analysis.

In this work we intend to start with a analysis similar to the one implemented in De Almeida *et al.* (2016), identifying the extrusion parameters that influence the process.

In order to reach the proposed objective, a number of studies were carried out to examine the extrusion process and the variables that can influence it. From this state-of-the-art research, a set of research hypotheses have been formulated, described in the next section in more detail. Results and discussion section comes after, the article ends with concluding remarks.

2. Aluminium Extrusion Process Background

The competitiveness in the metalworking industry increasing bring new challenges for the development of the global industry (Dudin, 2017), more specifically in the aluminium industry.

The aluminium is an extraordinarily versatile material. It can be shaped through various processes: casting, extrusion, forging, rolling, among others. It is also possible to apply various surface finishes to aluminium (coating, anodising, polishing, etc.). This makes its application attractive in distinct areas as air and road transports (Shyamu, 2015), maritime transports (Sreenivasulu, 2016), construction (Holtzer, 2013), food industry (Yeh, 2016), medicine (Cousseau, et al., 2017), electronics (Cousseau et al., 2017), etc.

Generically aluminium is a lightweight, soft and sturdy material. Its density is $2,70 \text{ g/cm}^3$ (approximately one third of the steel) and the tensile strength of aluminium alloys ranges from 70 to 700 MPa. These are some of the properties that make aluminium extremely competitive, when compared to other metals (Abal, 2007).

In the aluminium industry, the direct extrusion process plays an important role. Generally, involves large degree of plastic deformation, complex friction conditions, high temperature and high pressure. For example, Chen et al. (2015) studied the pyramid extrusion process to produce rectangular hollow aluminium, concluded that the flowing velocity, extrudate temperature, extrusion force, and welding pressure tend to increase as the increase of ram velocity.

The process starts with a sequence of furnaces - preheat, which allows to increase gradually the aluminium temperature (within the material specifications) so that a homogenisation heat treatment can be performed. Furthermore, the extrusion occurs under great stress and significant friction at the interface between the billet and the tool causing intensive production of heat, especially near the surface.

Donati et al. (2010) have shown that during the extrusion process adhesion friction generally occurs between the billet and the container resulting in inhomogeneous flow of the material towards the die, so that the centre of the billet flows to the faster die than the surface of the billet. Such behaviour is influenced through the processing parameters during extrusion influencing the end process parameter: the exit temperature. In this final extrusion step, the temperature rise in the die is influenced by the temperature progress in the billet during extrusion (Saha, 2000).

Considering that the exit temperature of extrudate profile is a measure of product quality (Matamoros, 1999) and, consequently, the reduction of material waste, several studies examine the conditions that influence de percentage of scrap (extrusion process) and the variables that can influence it were carried out.

In the next section, of this idea is considered and some research hypotheses have been formulated.

2.1. Billet length

Productivity can be defined by the maximum amount of material, in good conditions, that can be produced per unit of time (Saha, 2000). The processing conditions, not properly controlled, are usually directly associated with the amount of scrap. In addition, factors related to pre-extrusion potentiate the percentage of scrap produced, such as the cutting method used (Robbins et al., 2016). Still, the billet dimensions must also be considered. Several studies have reported the importance of billet length in the amount of scrap produced in the aluminium extrusion industry (Hajeeh, 2013; Tabucanon and Treewannakul, 1987).

One of the ways to maximize production in the aluminum extrusion industry is to maximize the length of the billet, to improve the press capacity and maximize the highest extrusion length (Saha, 2000).

Robbins et al. (2016) analysed the effect of the pressure in modern compact press designs, with longer containers embedded requiring greater billet length. According to them, when the size of the billet was increased, there was a considerable increase in the extrusion pressure (Figure 3). These pressures impose mean stress levels below the elastic limit of the maximum stresses that exceed the tensile strength at operating temperatures, resulting in some plastic deformation. Otherwise, Arif et al. (2002) studying how defects at different stages contribute to the final quality of extrusion product, found that high extrusion pressures may originate black lines which are burnt surfaces on the extruded, due to a local high pressure in the extrusion press.

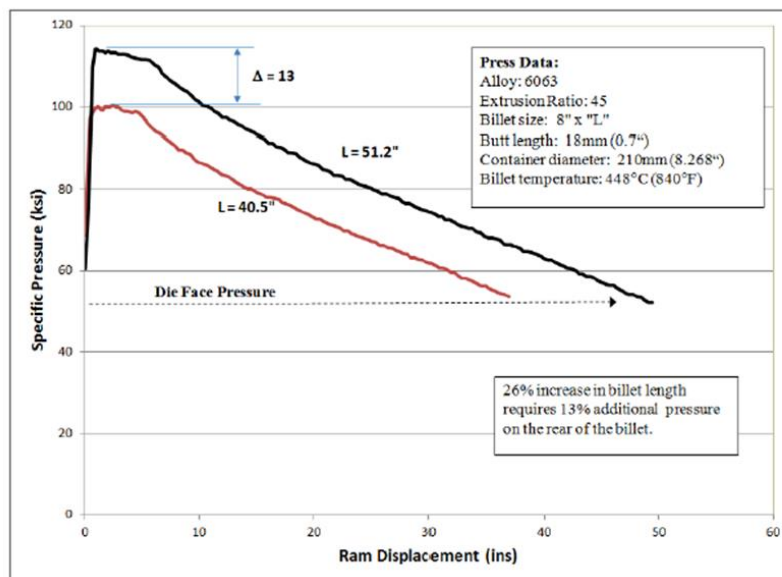


Figure 3 – Effect of billet length increase on specific pressure (Robbins et al, 2016)

Having into account the previous studies, the first hypothesis under investigation in this study is:

H1: The level of scrap produced is related to the length of the billet

2.2. Billet temperature

The friction conditions and the heat transfer are two major dimensions that play important roles in extrusion. High friction at the interfaces between billet and tool (container and die) leads to inhomogeneous material flow in the billet, during the extrusion process (Hatzenbichler, 2007). Thus, it is important that there is a temperature gradient along the length axis, to reduce the variation of the emerging temperature by keeping it under control.

Several authors describe billet temperature as the key parameter in the aluminium extrusion, for example Flitta and Sheppard (2005) and Bajimaya, et al. (2007). Firstly, the temperature evolution is alloy dependent. The flexible and hard aluminium alloys have the lowest and the highest temperature increase with, respectively, lowest and highest flow stress (Flitta and Sheppard, 2005). Otherwise, the same authors affirm that the flow stress is reduced if the temperature is increased and the deformation is, thereby, facilitated. At the same time, the maximum extrusion rate is reduced, because the localized temperature should be well below the incipient melt temperature (Bajimaya, et al., 2007).

Hatzenbichler (2007) have concluded that process parameters like initial billet temperature have only small influence on the back-end defect. Considering the extrusion limit diagram (Figure 4) with billet temperatures growth (and extrusion speed growth) the surface starts to deteriorate, identified in Figure 4 as inadequate surface (Peris, 2007). The authors considered that this behaviour is initially because of pick-up, and then via tearing, and eventually surface melting.

As illustrated in the Figure 4, poor mechanical properties are also identified for low billet temperature and speed extrusion values. Studying the relationships between thermal treatment, mechanical properties and microstructures of extruded aluminium alloys similar results were obtained in (Martins, 2008). Since, low exit temperatures are required to promote non-recrystallized structures. However, there is an increased risk of not achieving minimal mechanical properties. For this reason, a compromise should be considered between the use of higher temperatures, to benefit the mechanical properties, and decrease the exit temperature, to retard the formation of coarse grains.

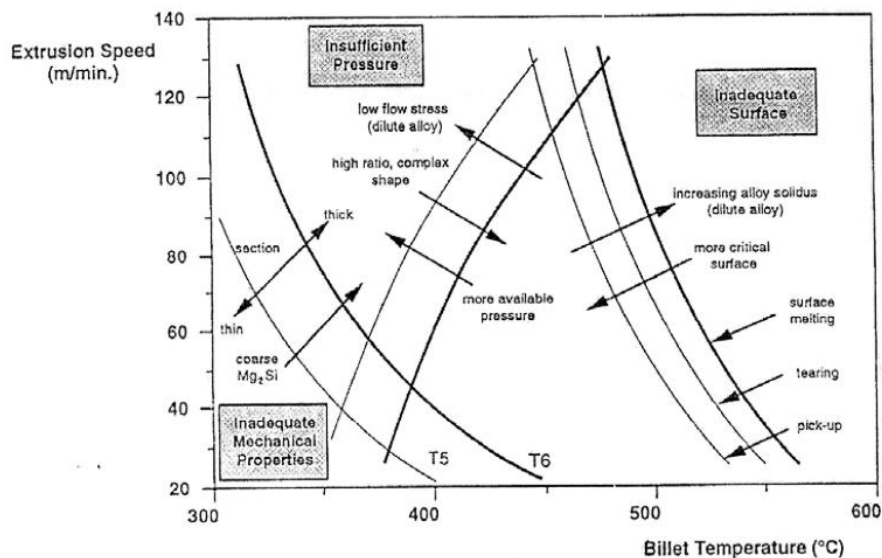


Figure 4 – Extrusion limit diagram (Peris, 2007)

Ab Rahim et al. (2015) affirms that the temperature of the billet is one of the variables to be taken into account during the extrusion process, because it influences the quality of the extruded product and, therefore, it is connected to the amount of defective material.

Given these revision, the below hypothesis (H2) it is being formulated:

H2: The level of scrap produced is related to the temperature of the billet

2.3.Ram velocity

The ram speed affects the extrusion time, which is used to decide the amount of heat that a waiting aluminium billet should be given to reach the preheat temperature, during the period of its waiting time (Bajimaya et al., 2007).

Extrusion speed is a very important variable because higher velocity generates greater deformation/stress imposed on the billet inside the container. Consequently, increase the energy of the system, which will be converted to thermal energy (Saha, 2000). Thus, the speed of the press is related to the temperature of the process, since the high rates of deformation can be significant and can produce more heat, which causes the temperature of the extrudate to increase, as we can see in the Figure 5 (Peris, 2007). In this work, the authors found a directly relationship between strain rate and extrusion speed, due to the friction at the die surface, considering that the flow stress is a function of shear rate.

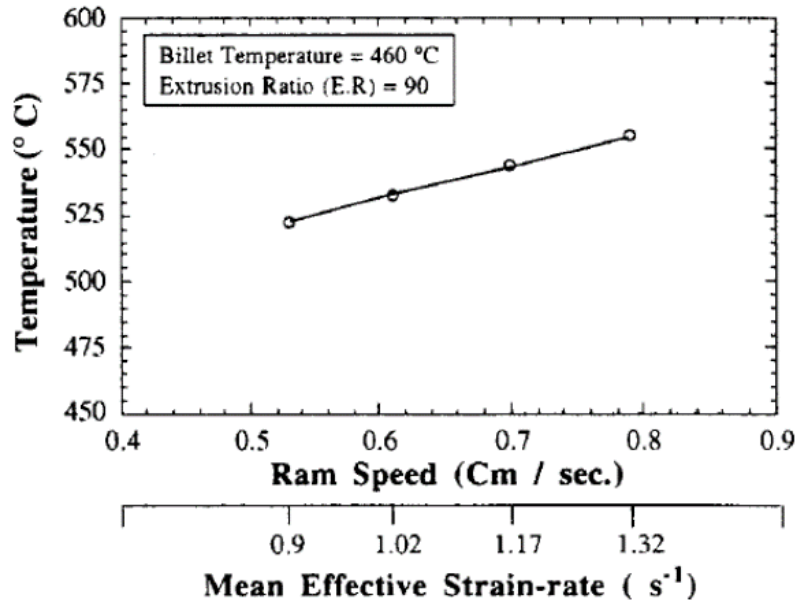


Figure 5 – Effect of ram speed on exit temperature (Peris, 2007)

In addition to a strong effect on extrudate temperature, the extrusion speed has also a high effect on the extrusion pressure, which is the primary limiting factor for a high extrusion throughput. Still, a slow speed reduces productivity at the expense of the extrusion efficiency, and a tool life can also be identified because of the prolonged contact time between the tool and the hot billet, promoting also heat transfer (Fang, 2009).

Observing the exit flow velocity of the profile in each plot, in Figure 6, it can be seen almost linear increases with the increase of ram velocity, which leads to higher temperature (Chen et al., 2015). In this paper, the authors attributed the effect of ram velocity to the appearance of back end defect.

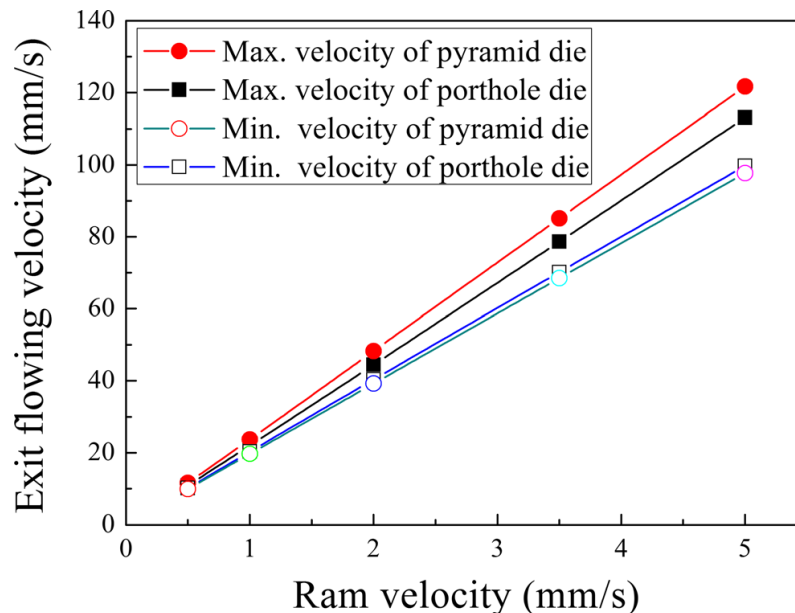


Figure 6 – Maximum and minimum flowing velocity at varying ram velocity (Chen, 2015)

For a given profile extrusion, the speed of the press is considered one of the critical parameters, which must be well controlled. Both, the risk of defects and the high demand for extrusion temperature and pressure, leave the press operator with no choice. According to plentiful authors, it is a variable that plays an important role, with respect to the surface quality of the profile and the productivity in the aluminium extrusion (Zhang et. al., 2012 and Flitta, 2004). Zhu et al. (2012) had reported that high speed worsens the surface of the product.

High enough exit speed increases hot shortness or cracking defects (Arif et al. 2002). The cracks may initiate if the billet does not cool fast enough causing localized melting. Otherwise, a limit is imposed on extrusion speed due to the undesirable coarse grain structure formed at the periphery of the extruded product (Fang, 2009); or by the appearance of tears on the surface of the extruded profile, which leads to an increase of non-conforming product (Arif et al., 2002, and Li et al., 2013).

Considering the studies related before, the third hypothesis under investigation in this study is:

H3: The level of scrap produced is related to the ram velocity.

2.4. Extrusion ratio

The extrusion ratio (ER) of a profile is the clear indication of the amount of mechanical work that will occur during the extrusion of a given profile (Saha, 2000). This factor directly represents the effective deformation in the extrusion process (Extrusion Deformation = $\ln(ER)$). It is expected that ER affects the flow stress of the metal and, consequently, also affects the maximum extrusion

pressure (Karabay, et al., 2003). Some authors (for example, Saha, 2000, and Karabay, et al., 2003) recognized that the increase in ER increases the extrusion pressure.

In addition Peris et al. (2007) have found that the temperature rise is ruled by the extrusion ratio, maintaining constant billet temperature and ram speed, as shown in Figure 7. Such behaviour results from material deformation due the friction at the die.

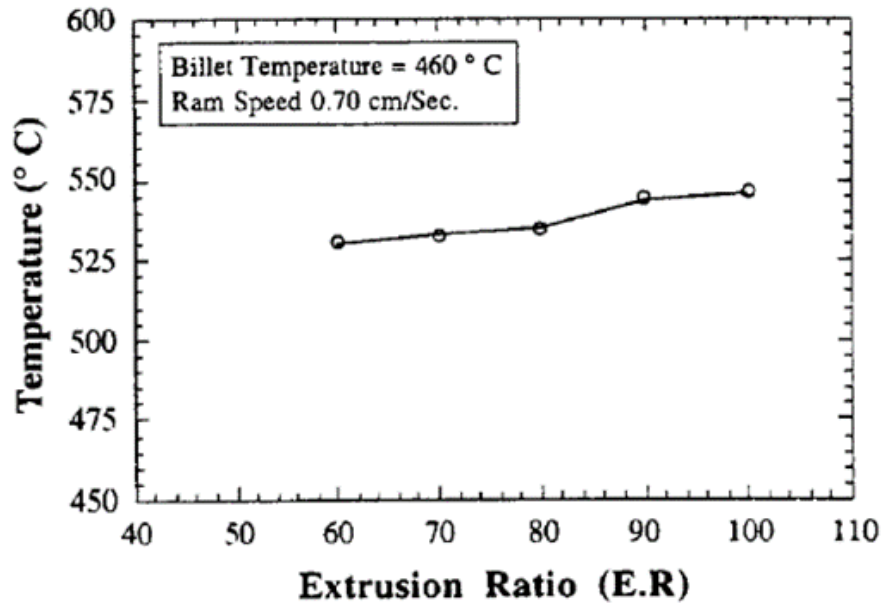


Figure 7 – Effect of extrusion ratio on exit temperature (Peris, 2007)

A strongest interaction between the extrusion ratio and operating conditions (initial billet temperature and ram speed) and, a moderate effect for the interaction between the geometrical condition (number of die cavities) were noticed by Abdul-Jawwad and Bashir (2011). However, it was not clear, in the literature, how the extrusion ratio influences the scrap production. Mahmoodkhani *et al.* (2014) studying the material flow and the formation of the transverse weld, relating that the extrusion ratio significantly impacted the length of the transverse coating. Thus, as the extrusion ratio increased the length of the cross-weld increase and the percentage of the original billet required implies the decrease of the scrap.

In line with what has been described, taking into account the literature, the forth hypothesis is:

H4: The level of scrap produced is related to the extrusion ratio

2.5.Profile exit temperature

The temperature obtained in the extrusion at the exit is the result of the initial temperature of the alloy billet, i.e., preheating temperature, plus the elevation temperature during the extrusion process. Fang et al. (2007) compared the evolution of the maximum workpiece temperature of different matrix profiles and ram velocities in the transient state of the extrusion.

Initially, Figure 8 shows a reduction of the maximum temperature during filling, due to the transfer of heat between the billet and the container, followed by a rapid increase in temperature. Such last behaviour is noticed as a combined result of large deformation and friction (Fang et al, 2009).

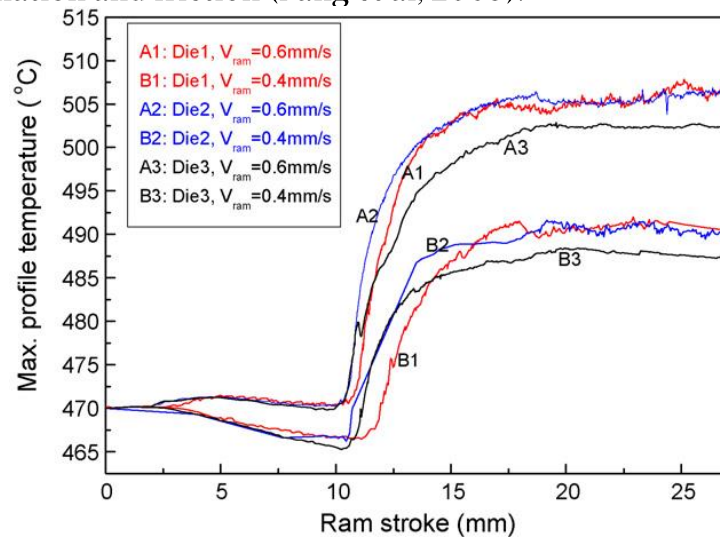


Figure 8 – Evolutions of the maximum temperatures of the workpiece through the different dies and extrusion speeds (Fang et al, 2009)

The exit profile temperature is clear affected by several extrusion factors (Flitta and Sheppard, 2005; Abdul-Jawwad and Bashir, 2011; Saha, 1998; and Farjad et al. 2011).

The results presented so far indicated that the main contribution to the profile outlet temperature comes from plastic works promoted by high extrusion rates, high initial billet temperatures and high ram speeds. In the Figure 9 can be seeing that the letters, from A to E, represents the variables: extrusion ratio (ER); number of cavities in the die (NOC); average profile thickness (THK); initial billet temperature (BLT); and ram speed (RS), respectively, a strongest effect of extrusion ratio on profile exit temperature is noticeable. In this figure, ER represents the total effective strain of the extrusion parameter.

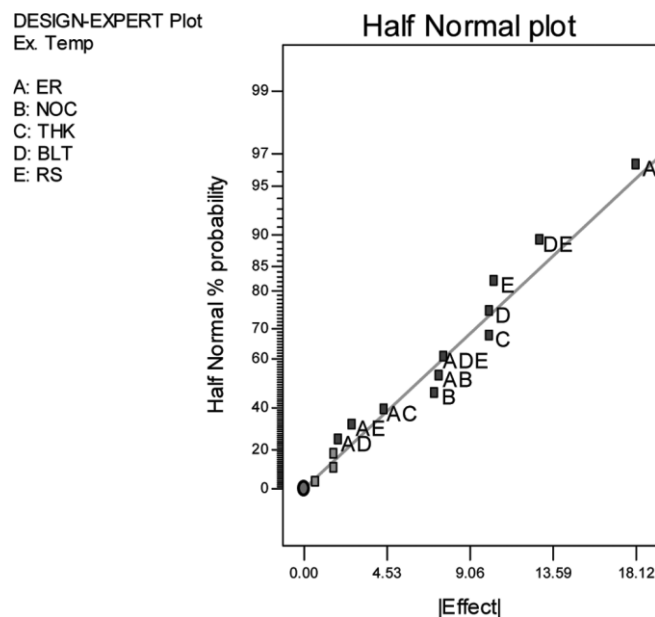


Figure 9 – Plot of extrusion parameters' effects on profile exit temperature (Abdul-Jawwad and Bashir, 2011)

Considering that high temperatures influence the surface quality of the profile and, consequently, its mechanical properties (Abdul-Jawwad and Bashir, 2011), we can consider that it has a relation with the percentage scrap produced. Thus, the temperature of the profile outlet represents the parameter of greatest interest in the aluminium extrusion industry, especially in alloys that are heat.

Surface defects should appear when the temperature of the extrudate exceeds a critical value, of the above-mentioned incipient melt temperature (Fang et al., 2007). Arif et al. (2002) explain that if the exit temperature is too high, tearing initially starts at the edges of the extrusion and, then, develops over the remainder of the surface; giving rise to what is commonly called fir-tree cracking or speed cracking.

According to Saha (2000), the quality of the product is affected by the temperature of the exit profile, as it influences the heat treatment processes and dimensional stability, causing defects during extrusion. These defects occur, due to the fact that the high exit profile temperature leads to tears and a "*somewhat shaky*" appearance during extrusion of the profile (Arif et al., 2002)

In this way, is expected that the profile outlet temperature significantly influences the percentage of scrap produced. Then, fifth hypothesis is:

H5: The level of scrap produced is related to the profile exit temperature.

3. Surface Defects

In this article, several process variables that influence the formation of defects in aluminium extrusions, industrial practice and experimental results were analysed. As already mentioned, extrusion is a process with many variables, some of which can be controlled by the operator (billet temperature, extrusion speed, billet length), while others cannot (exit temperature, for example).

We expect that the quality of the final product is affected by the interaction between the variables, resulting in different material characteristics. Some of these features may cause defects. ISO 9000: 2015 defines defects as: "*The non-fulfilment of intended usage requirements*". An extruded profile may be considered an unacceptable product if it does not meet standard or customer specifications.

Defects can be categorized in terms of appearance or in terms related to their mechanical properties (tensile strength, yield strength, hardness and ductility) of the extruded profile. The four groups considered by Arif et al. (2002) are: defective billets; faulty or unsuitable tooling; defects arising during extrusion; and, flaws resulting in the course of post-extrusion operations. Thus, product rejection can be traced to material defects, tool defects, processing anomalies, and post-extrusion defects and surface finishing (Qamar, 2004).

From the surface defects found in the literature, related to the extrusion variables, only those presented in Figure 9 were visually identified in the company ADLA Aluminium Extrusion S. A.

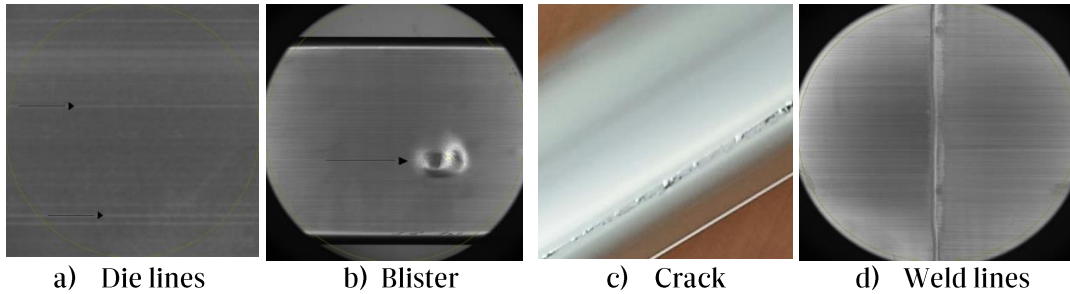


Figure 10 – Representative images, from a) to d), of the surface defects captured in ADLA company.

Arif et al. (2002) presents the definition of Aluminium Association to die line, as a “*longitudinal depressions or protrusions formed on the surface of the drawn or extruded material due to imperfections on the die surface*”.

As we can see in Figure 10 (image a)) the die lines are finer of thin film of extrudate which adheres to the die surface, during extrusion (Arif, 2002). However, the presence of impurities on the surface of the billet or die profile may aggravate the problem. These aggravated surface conditions are called micro die lines (Qamar, 2004).

The friction or differences between the diameter of the billet and the container may produce another defect. Friction can lead to a local increase in the temperature forming gas that expands, while the difference in diameter allows the gas or lubricant to be captured. These substances, when trapped below the surface of the material, give rise to another defect known as blister (or bubble) (Figure 10, b)).

Surface cracking defect (Figure 10, c)) occurs due to high temperature or high speed. The defect starts from the edges while developing towards the centre (Donati et al., 2005). The cause is attributed to the called secondary tensile stress of melting areas (Arif et al., 2002 and Qamar et al., 2004).

Lastly, to ensure adhesion between billets, and produce long sections of extruded profiles, the both surfaces (front and rear) are welded. This practice can lead to defects known as weld defects. Generally, this defect represents a discontinuity in the extruded product, represented in Figure 10, d).

4. Results and Discussion

The experiments were carried out in an industrial extrusion press, having a maximal force of 25 MN and maximal ram speed of 20 mm/s. Billet’s diameter was Ø203,20 mm and it was cut behind the furnace.

These experiments were performed using five types of dies, with different dimensions and geometry (randomly chosen). During extrusion process several parameters were measured:

- billet length – L_{Billet} ,
- billet temperature – T_{Billet} ,
- ram speed – N ,
- extrusion ratio – ER ,
- profile exit temperature – T_{Exit} .

Given the experience in ADLA Aluminium Extrusion S. A. when the ER increased, the mechanical properties of the extruded profile are affected. The

tensile strength increases as well as the hardness of the material increases, however a decrease in the percentage of elongation is observed. There is also an increase in the speed of the profile when the extrusion ratio is high, keeping the press speed constant during the extrusion process.

In order to verify the relationship between the extrusion process parameters similar to (De Almeida *et al.*, 2016) (considered as independent variables) and the percentage of scrap produced – %Scrap (dependent variable), a correlation matrix was calculated through the SPSS software.

From the obtained results, in Table 1, it was concluded that the variables N and T_{Exit} do not have a significant correlation with %Scrap. $T_{Billete}$ show a significant and positive correlation with the variable %Scrap, then we can consider that the billet temperature could be an explanatory element of a scrap increment during the aluminium extrusion process. On the other hand, the variables ER and L_{Billet} has a significant and negative correlation with the %Scrap, then the billet length and extrusion ratio could be explanatory parameters of a scrap decrement during the aluminium extrusion process.

Table 1 – Pearson Correlations

		L_{Billet}	T_{Billet}	N	ER	T_{Exit}
%Scrap	Pearson Correlation	-0.398**	0.686**	0.096	-0.665**	0.043
	Sig. (2-tailed)	0.004	0.000	0.505	0.000	0.765
	N	50	50	50	50	50

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

According to this results can be considered verified the first, the second and the fourth investigation hypothesis, i.e., the level of scrap produced in this extrusion aluminium industrial process is related to the length of the billet, the temperature of the billet and the extrusion ratio.

In order to study if the relationships of the parameters under analysis affects the percentage of scrap, considering together, a multivariate linear regression model was tested in agreement with the hypothesis formulated. Then the dependent variable is the percentage of scrap and the extrusion parameters are the independent variables. In order to exclude non-significant parameters, the stepwise method is considered. The model found as an adjusted R square of 0.686, once the constant of the liner model obtained is not significant, a similar model without the constant is considered. The final multivariate linear regression model summary is presented in Table 2.

Table 2 – Multivariate Linear Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
4	0.979	0.959	0.956	5.05184	1.681

The model has an Adjusted R Square 0.956. From this way, it can be said that the four independent variables explain 95.6% of the variance occurred on the dependent variable % Scrap.

Table 3 – Multivariate Linear Regression ANOVA test

	Model	Sum of Squares	df	Mean Square	F	Sig.
4	Regression	27553.284	4	6888.321	269.907	0.000
	Residual	1173.968	46	25.521		
	Total	28727.252 ^d	50			

The significance value of the ANOVA test is approximately zero, Table 3, then the estimated linear multivariate model is highly significant, i.e., the variables have a significant effect on the variation of the dependent variable (%Scrap).

Table 4 – Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
4	T_{Billet}	0.123	0.011	2.303	11.612	0.000	0.023	44.266
	ER	-0.141	0.018	-0.364	-7.809	0.000	0.410	2.442
	L_{Billet}	-0.024	0.005	-0.838	-4.673	0.000	0.028	36.167
	N	-1.086	0.405	-0.305	-2.678	0.010	0.069	14.571

The results obtained with this model, presented in Table 4, are similar with the obtained with the study association between variables. Then it can be concluded that the independent variables with major impact are ER, L_{Billet} , T_{Billet} , and N, respectively. Then, having into account the hypothesis formulated:

- H1: The level of scrap produced is related to the length of the billet
- H2: The level of scrap produced is related to the temperature of the billet
- H3: The level of scrap produced is related to the extrusion speed.
- H4: The level of scrap produced is related to the ram speed
- H5: The level of scrap produced is related to the profile exit temperature.

Can be considered verified the first, the second and the fourth investigation hypothesis, i.e., the level of scrap produced in this extrusion aluminium industrial process is related to the length of the billet, the temperature of the billet and the ram speed. The extrusion speed, according to these results, are removed from the model, for not being consider significant to explain the percentage of scrap.

The same results for these coefficients are obtained using a bootstrap technique with 1000 samples, obtained by simple sampling method and considering a confidence interval level of 95%, reinforcing their validity.

This way it is possible to predict the percentage of scrap using the formula:

$$\%Scrap = 0.123 T_{Billet} - 0.141 ER - 0.024 L_{Billet} - 1.086 N$$

Analysing the Standardized Coefficients is possible compare the contributions of the variables, and we can conclude that the variable with greater contribution for the growth of waste is the Billet temperature T_{Billet} , followed by the length of the billet L_{Billet} , which contribution is in opposite direction of percentage of scrap. The other two significant variables have similar contributions, smaller than the previous ones, but also in in opposite direction.

Considering the Unstandardized Coefficients is seen that the increase of 1 unit in the variable T_{Billet} implies a grown up in the percentage of scrap in 0.123 units. The same interpretation can be done for the remaining variables.

Linear regression models require that residuals had a normal distribution with zero mean and constant variance, and that they must be independent.

Using the One-Sample Kolmogorov-Smirnov Test, an Asymptotic Significance value (2-tailed) with Lilliefors Significance Correction of 0.043 is calculated, which is smaller than 5%, conducting to the rejection of the normality of the residuals. But, if the significance value considered was 1% this normality is not rejected. Besides that, the Skewness coefficient of the residuals distribution is around 1.78 and the Kurtosis coefficient is around 0.42, then the distribution can be considered approximately normal. The mean of the residuals is - 0.0092621, very close to 0.

Concerning to independence Durbin-Watson statistics, presented in Table 2 **Erro! A origem da referência não foi encontrada.**, is close to the value 2, and then there is no evidence to consider that the residuals are correlated.

When the independent variables are highly correlated to each other (multicollinearity) the analysis of the adjusted regression model can be confusing. Once Tolerance is around next 0, and some VIF (Variance Inflation Factor) values are also larger than 5, there is indicators of multicollinearity, being this fact a limitation of this model.

5. Conclusions

In this work it was established that to obtain good products during the extrusion process it is necessary to know the variables that affect the final quality of the product. Regarding the variables under study, it was clear that there is an interdependence relation of the independent variables with the percentage of scrap produced in the extrusion process (dependent variable). Regarding the variables that most influences the percentage of scrap, when an univariate approach is considered (Pearson linear correlations) are, respectively, extrusion ratio, length of the billet and temperature of the billet. Having into account the multivariate approach the same variables are considered pertinent, besides that

extrusion speeds also significant. The results with bootstrap are the same, reinforcing their validity.

Finally, optimizing the extrusion process through better knowledge/control of the variables allows obtaining productivity gains, minimize the amount of waste and fundamentally improve the quality of the product.

Held this project, it is possible to conclude that the initially set targets were effectively reached. At present, and the result of recognition of the importance that the study of extrusion parameters ADLA Aluminum Extrusion SA, acquired a new software that allowed positively contribute to the optimization of these variables and ultimately to reduce the percentage of scrap produced.

In short, it can be concluded that with this study several solutions have been found, some of which have been implemented successfully, resulting in gains for organization in terms of product improvement, delivery times and, fundamentally, waste reduction. However, it is necessary to solidify the implemented strategies, as well as to take into account that improving the process is central to continued success, and the intervention and interaction of all employees of the company is crucial.

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3. 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 it is concluded 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 live in a digital era where the media and transportation create a global market (Arif, 2005). 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. Barreto quoted by Soccol (2011) states that combating waste is a goal to be achieved. One way to identify waste is to keep the process under control, and to control it, is required to know the whole process. According to Campos (1999), "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". This is the only way to increase productivity, which is defined by Campos (1999) as "to produce more and more and/or better with less and less".

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 non-conformities (Nogueira, 2010), minimizing the quantity of scrap.

In the same line of thought Deming quoted by Pires (2016), 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. On the other hand, Juran and Godfrey (1998) associate the concept of quality with the concept of management and assign two definitions to it.

Quality defined through the level of consumer satisfaction (products according to specifications, or quality such as absence of defects (fewer defects = less costs)) (Junior, 2014). 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 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 in 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 (Pacheco, 2012).

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 (Meireles, 2006).

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 on 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 (Mengesha, et al, 2013).

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.

According to Tar & Sabater, 2004, although there are a great variety of quality tools, the most important are the seven basic quality tools, suggested by Ishikawa, namely:

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 (D. Montgomery, 2009). 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 (Godina, 2013).

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 (Marques, 2016). 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 (Sherman, 2012).

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 charts 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 (D. Montgomery, 2009). 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 (Montgomery, 2009).

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 (Montgomery, 2009). 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 (Mystica, 2015). 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 **Figure 11** represent the secondary causes.

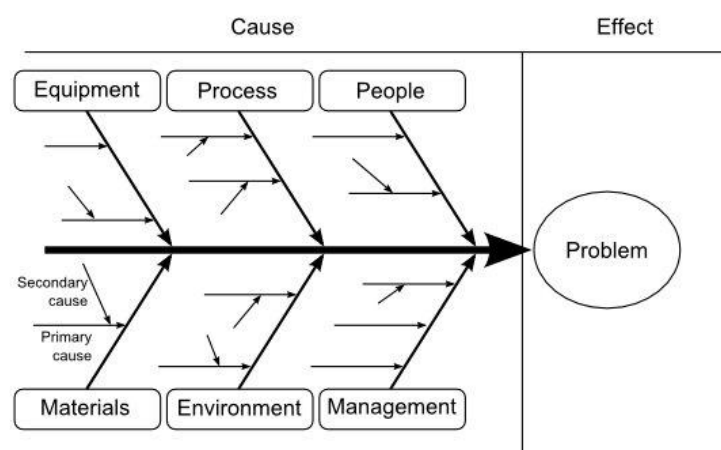


Figure 11 – Cause and effect diagram (Source: Mystica, 2015)

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 (Mystica, 2015):

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., analysing the problems by different data groups and analysing the before and after impact of the changes (Mystica, 2015).

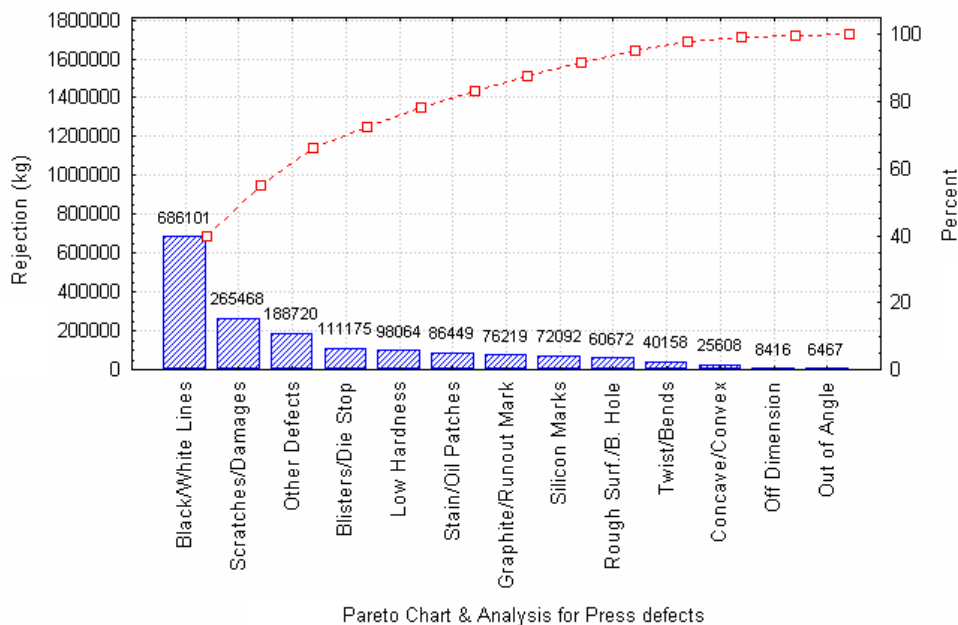


Figure 12 – Pareto Chart for causes of default rejections. (Source: Arif, 2005)

Figure 12, presented by Arif (2005), illustrates a Pareto Chart for causes of rejection due to defects caused during extrusion. 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 "causes" 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. According to Montgomery (2009), 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.

Table 5 presents an example of a check sheet, used in surveying the occurrence of defects in the monthly production of a factory. These type of sheets allow analysing evidences of eventual production problems.

Table 5 – 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 Figure 13 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 (Montgomery, 2005).

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."(Oakland, 1991)

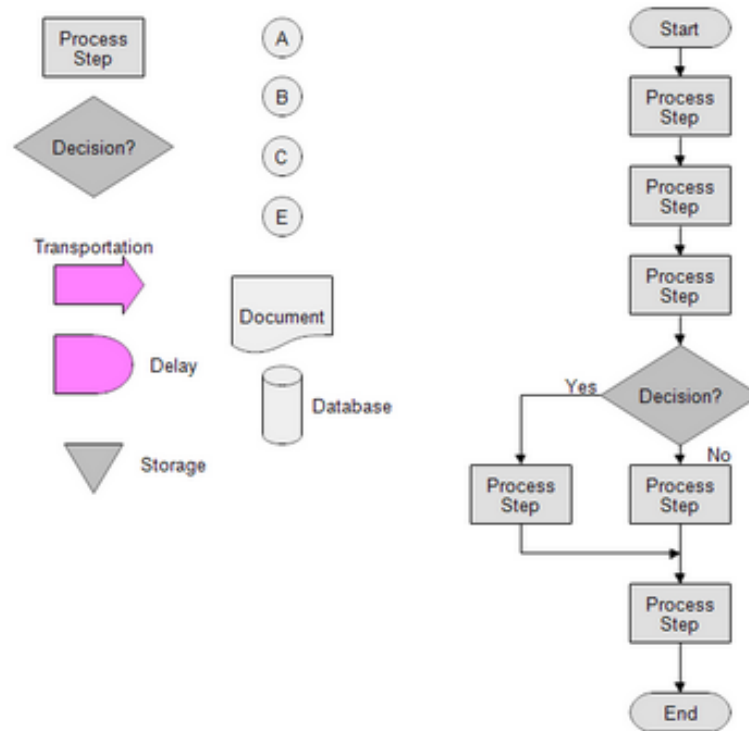


Figure 13 – Flowchart example (Source: Mystica, 2015)

Figure 13 illustrates a flowchart and some of the forms used in its construction and the meaning.

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 Figure 14).

Analysing 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 (Kurokawa, 2002). 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.

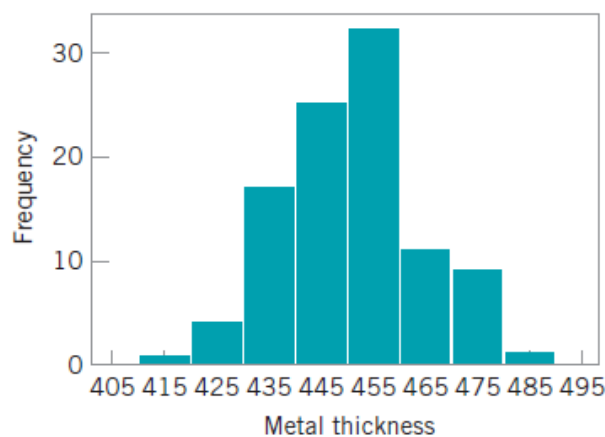


Figure 14 – Histogram example (Source: Montgomery, 2009)

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 (y_i, x_i) , for $i = 1, 2, \dots, N$. The shape of the scatter diagram usually indicates which type of relationship can exist between the two variables (D. C. Montgomery, 2009).

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 Figure 15, 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 (Oakland, 1991). In the two scatter plots in the left, it is observed a linear correlation between the variables. In the first case positive, and negative in the second. The last (in the right) scatter plot does not indicate the existence of any correlation between the variables.

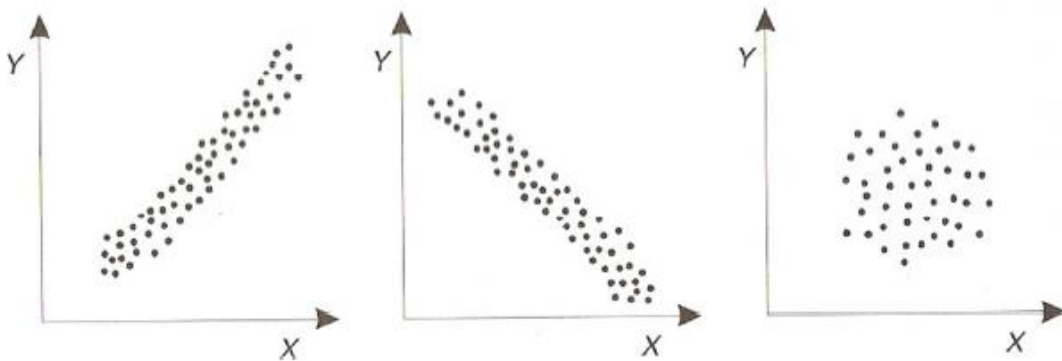


Figure 15 – Types of correlation (Source: Teixeira, 2016)

2.7 Control charts

A control chart is defined as a graphical representation of a quality characteristic that is recorded over certain time intervals (Pereira and Requeijo, 2012).

The graph shows information of the mean value of the process (\bar{x}), represented by a centre line and two other reference lines, respectively representing the Upper Control Limit (UCL) and Lower Control Limit (LCL).

According to Pereira and Requeijo (2012), as quoted by Teófilo (2014), to assume that a process is under statistical control, all samples must be included in the zone defined by the limits. 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 behaviour. 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 analyse 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 \bar{x} , charts of amplitude R and charts for individual values.

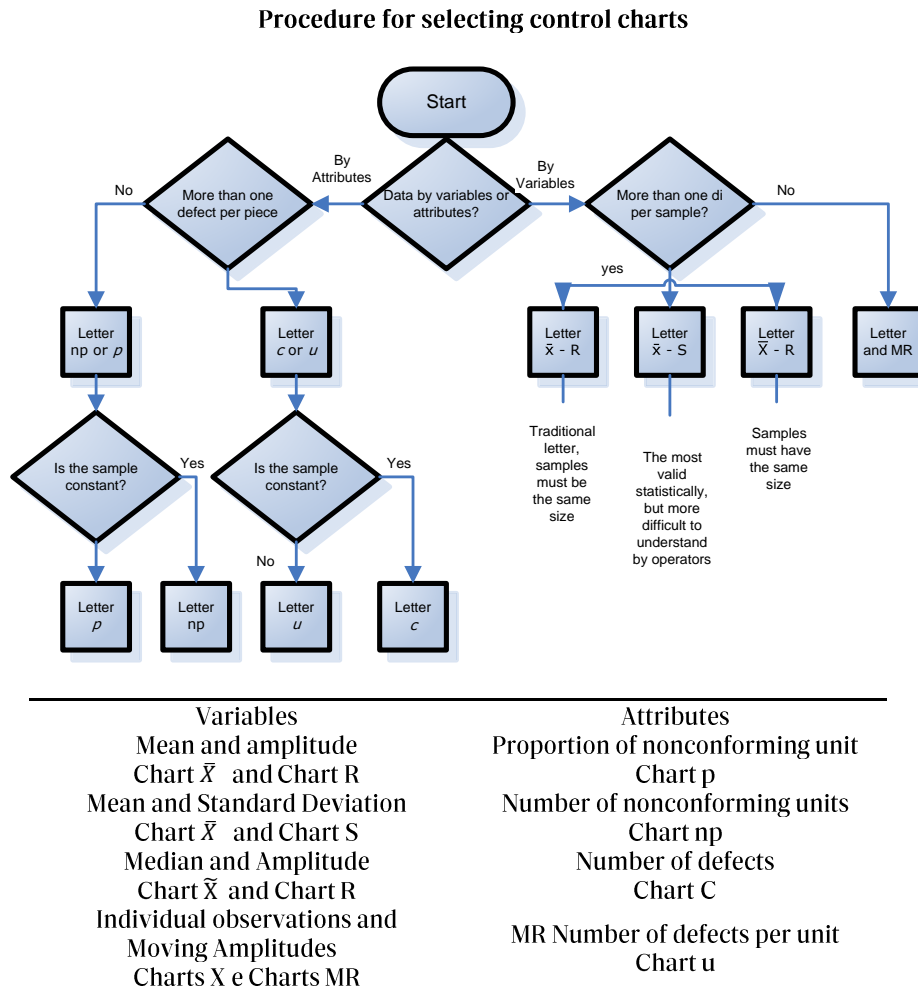


Figure 16 – Types of control charts and selection process (Source: Adapted from Godina, 2013)

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 Figure 16.

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 Montgomery (2005).

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.

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

where,

\bar{X} = Mean sample;

s = Standard deviation sample;

x_i = i -th element of the sample i , with $i = 1, \dots, n$;

n = number of elements or sample size .

Knowing that \bar{X} it is normally distributed, with mean μ and standard deviation $\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}}$. 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 $1 - \alpha$, where α is the probability of error. A confidence interval of $100(1 - \alpha)\%$ is established from two limits, and the probability of the true value of the parameter being included within the interval is $100(1 - \alpha)\%$ (Ribeiro, 2012).

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 $100(1-\alpha)\%$ 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:

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

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

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

In order 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:

$$\bar{R} = \frac{R_1 + R_2 + \dots + R_n}{n}$$

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

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:

$$\sigma = \frac{\bar{R}}{d_2},$$

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

Table 6 – Values of constants D4, D3, d2, A2 used in the construction of control charts

n	2	3	4	5	6	7	8	9	10	15	20
D4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78	1.65	1.59
D3	0	0	0	0	0	0.08	0.14	0.18	0.22	0.35	0.42
d2	1.13	1.69	2.06	2.33	2.53	2.70	2.85	2.97	3.08	3.47	3.74
A2	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

$$A_2 = \frac{3}{\sqrt{n} d_2}$$

it is obtained the control limits for the means:

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

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:

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

where:

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

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

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

Considering $D_4 = 1 + 3 \frac{d_3}{d_2}$ e $D_3 = 1 - 3 \frac{d_3}{d_2}$ in equation (8), it is obtained the control limits for the amplitudes:

$$\begin{aligned} LSC_R &= D_4 \bar{R} \\ LIC_R &= D_3 \bar{R} \end{aligned}$$

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. According to Rotondaro cited by Alexandre (2011), to study the capacity of the process it is necessary to know the specifications.

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 centreline, 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} (Fernandes, 2013).

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 index 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 $(C_{pk})_i = \frac{\mu - LIE}{3\sigma}$ and $(C_{pk})_s = \frac{LSE - \mu}{3\sigma}$.

Some observation can be made regarding the indexes C_p e C_{pk} (Montgomery, 2009), 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 6σ - 99.73% of the products produced and that the defective fraction is 0.27%.

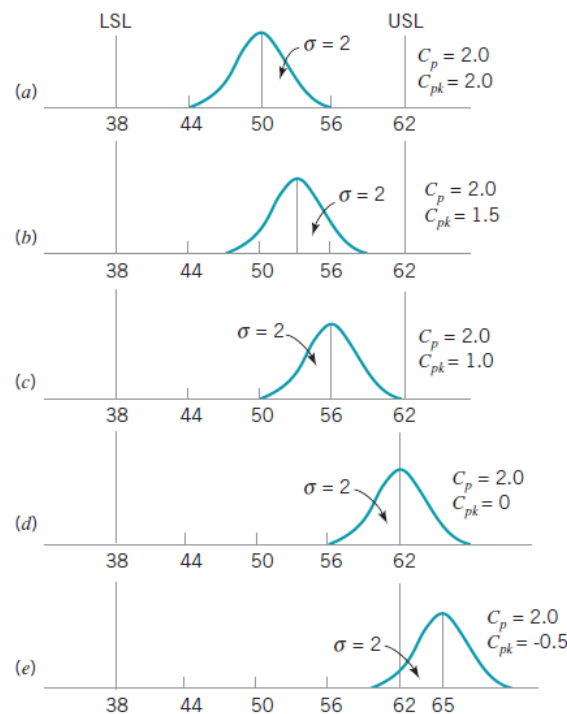


Figure 17 – Relationship between C_p e C_{pk} (Source: Montgomery, 2009)

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 non-conformities 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 analysing 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 Figure 18 is presented the Aluminium Extrusion Flowchart of the company ADLA, S.A..

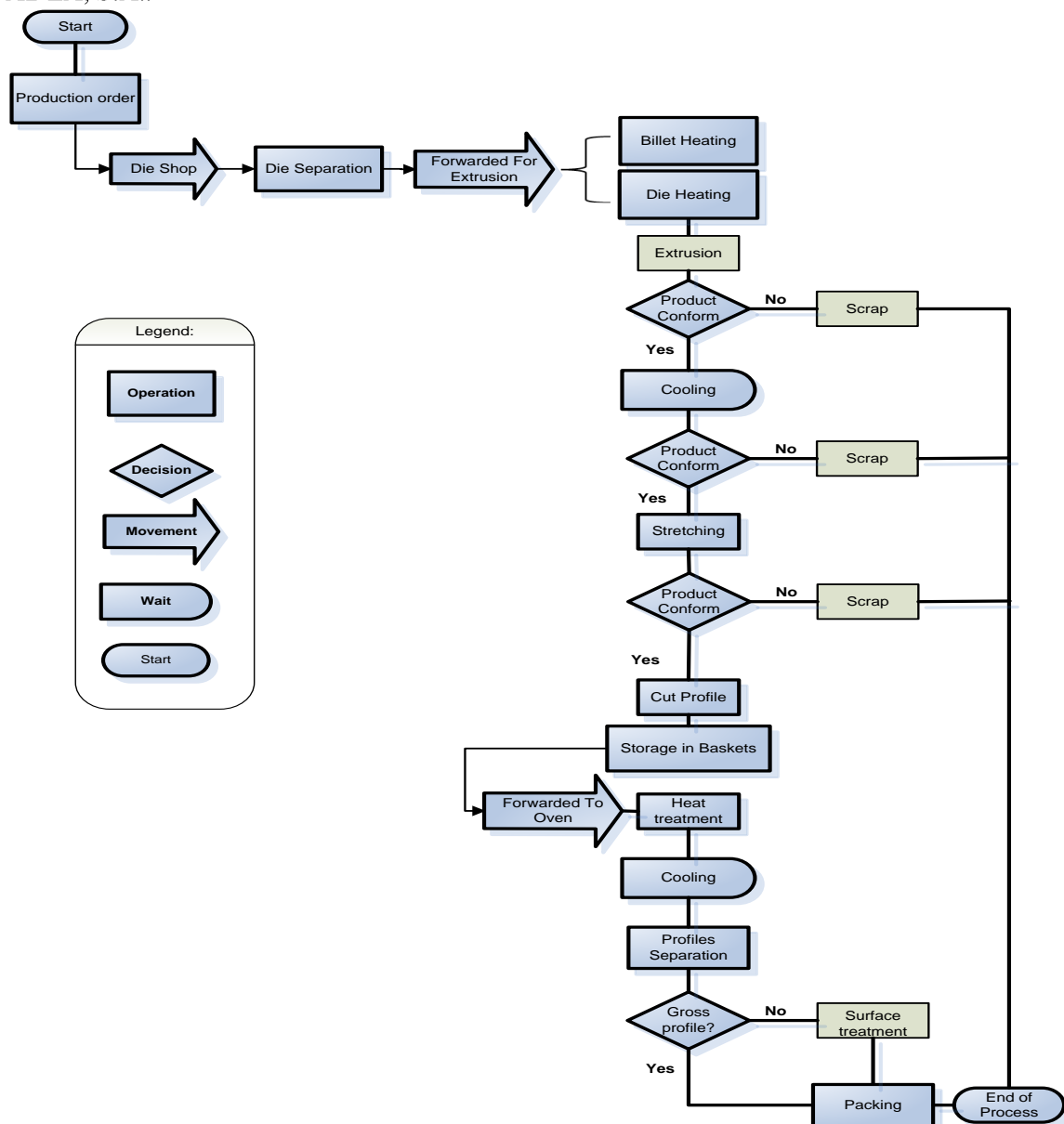


Figure 18 – Aluminium Extrusion Flowchart of ADLA, S.A.

Aluminium extrusion is a process in which a press force 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 (Figure 19). 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 (Figure 21) and the process starts with a simple cleaning of the surface, to remove dirt and some surface impurities that may exist (Figure 20).



Figure 19 – Raw material

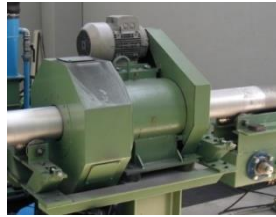


Figure 20 – Aluminium brushing/cleaning



Figure 21 – Feeding Ramp

After being cleaned, the billets enter the preheating furnace (Figure 23) 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).



Figure 23 – Heating Oven



Figure 22 – Cutting 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 (Figure 22) and transported (Figure 25) 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.

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.



Figure 25 – Billet Transporter



Figure 24 – Hot Saw

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 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 (Figure 27), 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 (Figure 27), the bars are cut (Figure 24) into bars of lower length and placed in containers (Figure 29) which are transported to the aging furnaces (Figure 28), if the profiles are aged, or for shipment.



Figure 27 – Stretcher



Figure 26 – Final Saw

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.



Figure 28 – Aging furnaces



Figure 29 – Containers

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 8 – 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 analysed.

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 (Figure 30) 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.

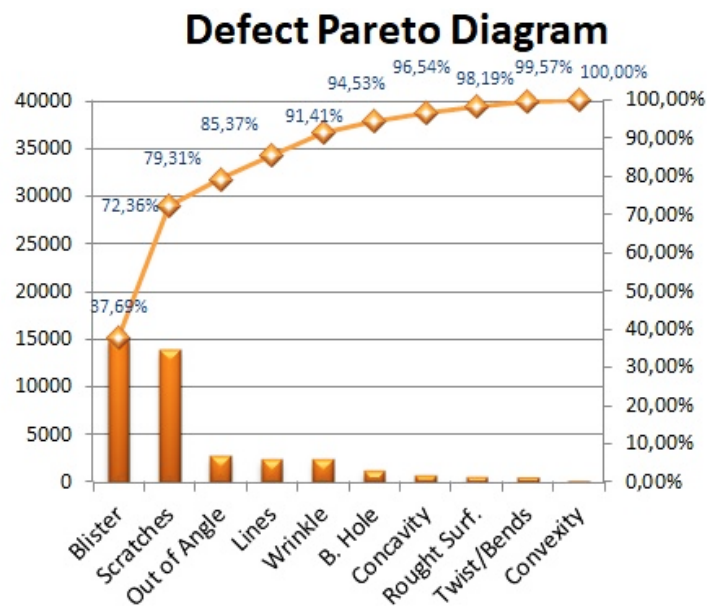


Figure 30 – Pareto diagram for NC in ADLA, S.A.

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 Figure 31.

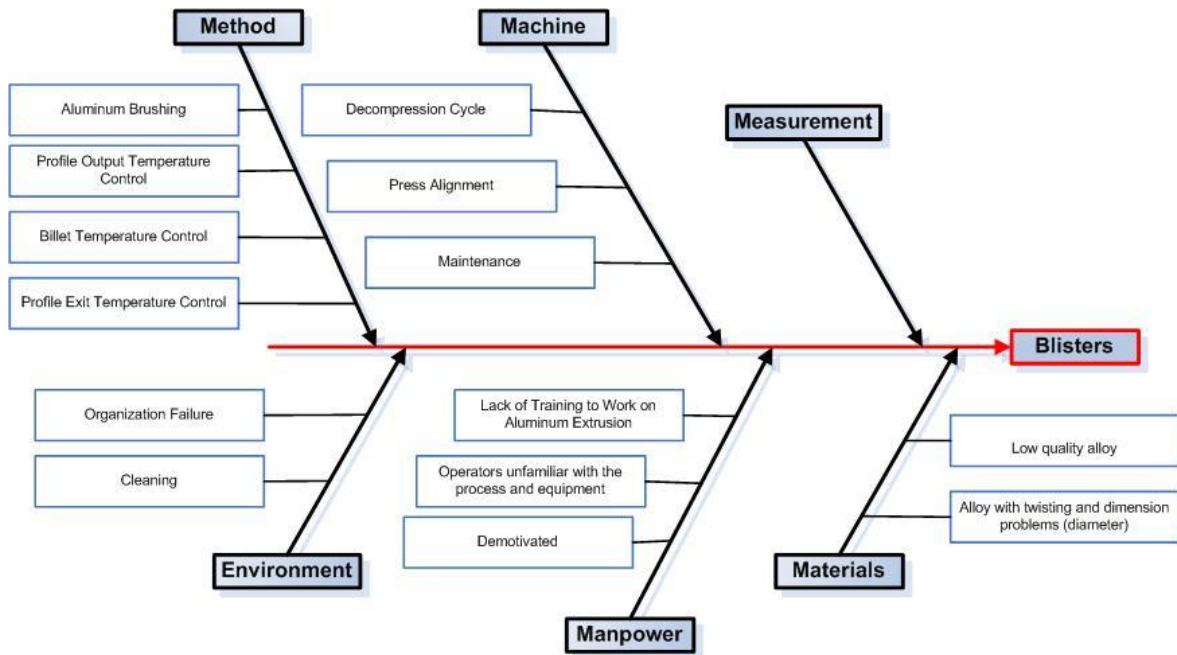


Figure 31 – Cause and Effect Diagram NC “Blisters”

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
1	2	3	4	5

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

Method	Evaluation	Machine	Evaluation
Time at maximum pressure	1	Decompression cycle	1
Aluminium Brushing	3	Press Alignment	2
Temperature control at profile	2	Maintenance	3
Billet temperature control	2	Lack of Lubrication	3
Container temperature	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	5	Low quality alloy	1
		Billets with problems	3
Average	5.00	Average	2.00

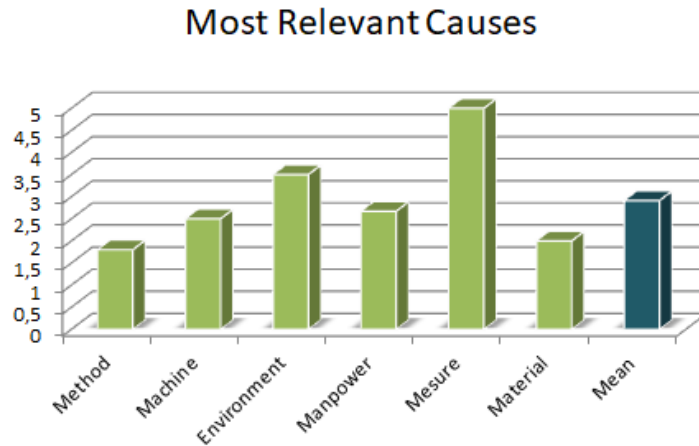


Figure 32 – Causes of the NC "Bubbles"

Based on the data collected, we created the graph in Figure 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 analysing 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 allows 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

According to Lopes (2011) the time at maximum pressure can be defined as the time at which the hydraulic pressure remains at its maximum value. 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.

Figure 33 shows a graph, typical for aluminium alloys, where it is possible to observe the extrusion pressure as a function of the piston movement. Meng (2010)

identifies through this graph, six main stages that occur during the extrusion of a billet. 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 characterised 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.

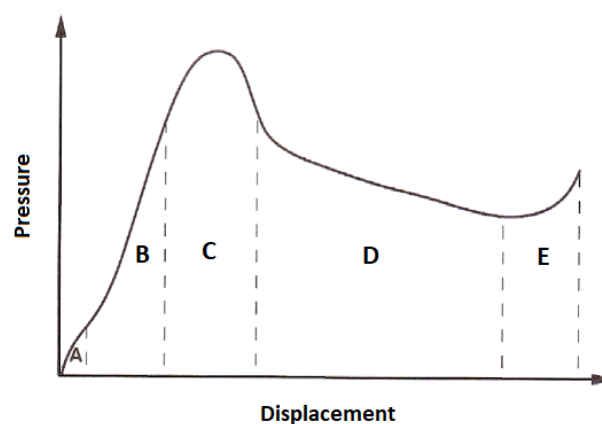


Figure 33 – Extrusion pressure chart (Source: Meng, 2010)

Analysing the control charts means and amplitudes, through Figure 34 and Figure 35, it is possible to observe that, for the variable under study (time in the maximum pressure), the process does not present an adequate statistical behaviour. 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 Figure 35, where it can be seen that there are points outside the control limits.

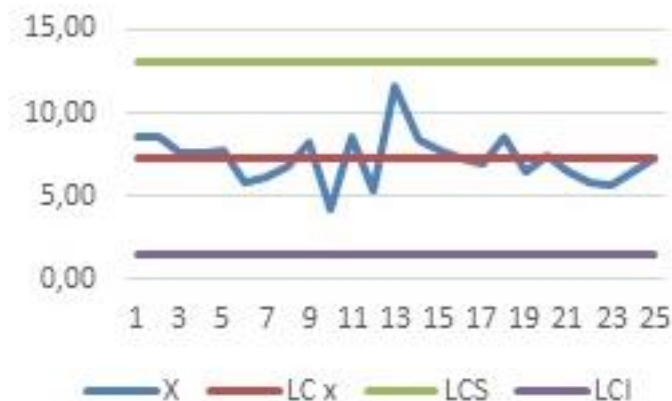


Figure 34 – Average Chart (\bar{x}) - Time at Maximum Pressure

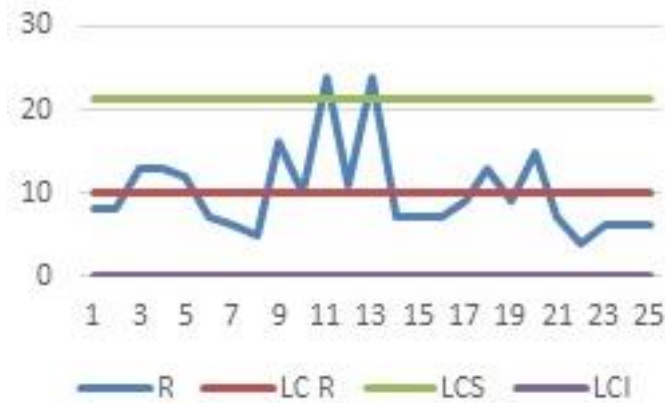


Figure 35 – Amplitude Chart (R) – Time at Maximum Pressure

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 Figure 29) 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 (Robbins, 2014).

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 50°C 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 (Lopes, 2011).

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

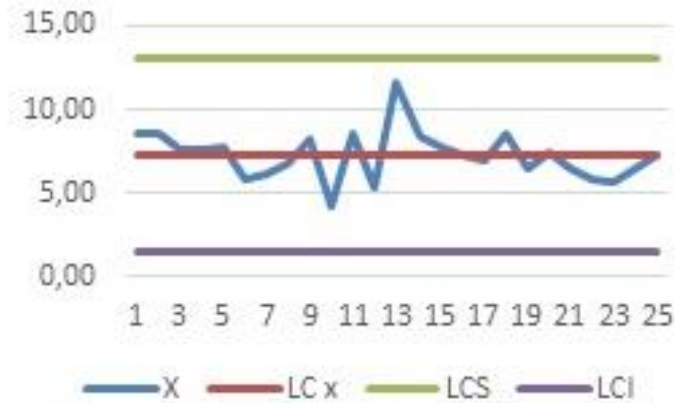


Figure 36 – Average chart (R) – Container temperature

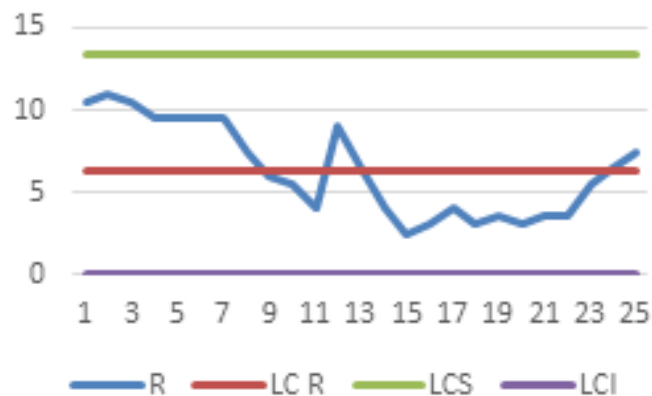


Figure 37 – Amplitude chart (R) – Container temperature

From the analysis of the Figure 36 and Figure 37 it will be seen that in general the values are within the control limits.

4. Conclusions

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.

With this work it was possible to verify that in order to use the quality tools in a consistent and effective way, it is necessary to improve the equipment maintenance level.

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4. CONCLUSIONS

This work is based on the topic of aluminium extrusion, in particular in the productive process in ADLA Aluminium Extrusion S. A.

Starting from the beginning that these aluminium extrusion process produces an important amount of scrap, and having the goal of improve the productivity, profits and optimize the quality of product, these work has two parts.

First, in order to reduce the large amount of scrap in ADLA, was made an evaluation to extrusion variables, with resisted values. It was possible to observe an evident relation between these variables and the percentage of scrap produced in the extrusion process. Besides that, it was conclude that the variables that most influences the percentage of scrap are, respectively, extrusion ratio, length of the billet and temperature of the billet. Other variables influencing the extrusion process, not considered in the study, were identified in the literature, but they are not initially measured in the company. In this sense the importance of this monitoring capacity was advised to the company, who has already acquired software for this purpose. This has created in the company an unlimited improvement potential, which is intended to be achieved in the future works.

Finally, optimizing the extrusion process through better knowledge/control of the variables allows obtaining productivity gains, minimize the amount of waste and fundamentally improve the quality of the product. This is what we intend to achieve in the second part of the developed work. During this part of the research, we began studying the importance of the quality tools to help us solve a waste problem, that is, a problem of high percentage of scrap. The application of appropriate quality tools and techniques allowed the suggestion and implementation of corrective and preventive actions. The Pareto diagrams allowed to identify the most frequent NCs, through brainstorming it was possible to draw Ishikawa diagrams for the problems. Then it was possible to hierarchize the causes for waste. The training of employees was essential, as they familiarize them with the new processes and bring them closer to the company. It was possible to verify throughout the study that the operators cause several defects, because disinformation, which have costs to the company. Thus, this study was essential to learn simple but useful techniques, cheap to implement and with profitable results.

Appendix A. Checklist for the types of errors observed in ADLA, S.A.

TYPE OF DEFECTS	Month								TOTAL	ACUMULATED VALUE (€)	ACUMULATED %
	January	February	March	April	May	June	July	August			
Blisters	1806,26	1664,97	3048,39	1718,61	1926,62	1728,51	2314,61	908,78	15116,76	15116,76	37,69%
Scratches/Damages	1093,2739	1989,3144	2475,2364	2027,269	2509,4751	1818,5235	1550,447	443,01009	13906,55	29023,31	72,36%
Out of Angle	48,306	164,20105	209,4429	528,64975	441,99865	417,7465	815,18935	161,3159	2786,85	31810,16	79,31%
Lines	332,70549	146,357	432,66871	195,34703	262,15458	484,6031	423,79276	152,09125	2429,72	34239,88	85,37%
Wrinkle	434,3888	107,2724	393,58202	347,69823	499,4172	239,07715	224,7514	176,5846	2422,77	36662,65	91,41%
Hole B.	1021,43	66,93	16,78	78,45	45,18	18,23	3,02	3,17	1253,19	37915,84	94,53%
Concavity	0	104,086	0	172,34648	0	38,30985	479,63265	9,7128	804,09	38719,92	96,54%
Rough Surf	14,922	117,7874	70,64317	126,826	4,9855	56,55394	187,86079	85,8349	665,41	39385,34	98,19%
Twist/Bends	226,2946	0	117,325	207,802	0	0	0	0	551,42	39936,76	99,57%
Convexity	59,9014	0	0	19	83,8422	10,056	0	0	172,80	40109,56	100,00%
Total	5037,48	4360,92	6764,07	5422,00	5773,67	4811,62	5999,30	1940,50	40109,56		
PRODUCTION	600.753	474.753	635.409	510.125	668.090	539.095	610.733	263.703	3701.908		

Appendix B. Time at Maximum Pressure (5 observations of the same profile on different days with 25 Billets at each observation)

Number of Billets	Observations					Average Data				Amplitude Data			
	1	2	3	4	5	\bar{x}	LC	LCS	LCI	R	LC	LCS	LCI
1	7	6	9	14	7	8,60	7,25	13,09	1,41	8	10,12	21,40	0
2	7	6	9	14	7	8,60	7,25	13,09	1,41	8	10,12	21,40	0
3	7	1	9	14	7	7,60	7,25	13,09	1,41	13	10,12	21,40	0
4	7	1	9	14	7	7,60	7,25	13,09	1,41	13	10,12	21,40	0
5	7	2	9	14	7	7,80	7,25	13,09	1,41	12	10,12	21,40	0
6	7	7	9	2	4	5,80	7,25	13,09	1,41	7	10,12	21,40	0
7	3	7	9	5	7	6,20	7,25	13,09	1,41	6	10,12	21,40	0
8	4	8	9	6	7	6,80	7,25	13,09	1,41	5	10,12	21,40	0
9	5	18	9	7	2	8,20	7,25	13,09	1,41	16	10,12	21,40	0
10	11	1	1	7	1	4,20	7,25	13,09	1,41	10	10,12	21,40	0
11	26	3	2	8	4	8,60	7,25	13,09	1,41	24	10,12	21,40	0
12	11	0	4	8	4	5,40	7,25	13,09	1,41	11	10,12	21,40	0
13	17	3	27	8	3	11,60	7,25	13,09	1,41	24	10,12	21,40	0
14	10	7	4	10	11	8,40	7,25	13,09	1,41	7	10,12	21,40	0
15	9	5	4	10	11	7,80	7,25	13,09	1,41	7	10,12	21,40	0
16	7	4	4	10	11	7,20	7,25	13,09	1,41	7	10,12	21,40	0
17	7	4	2	11	11	7,00	7,25	13,09	1,41	9	10,12	21,40	0
18	15	4	2	11	11	8,60	7,25	13,09	1,41	13	10,12	21,40	0
19	3	5	2	11	11	6,40	7,25	13,09	1,41	9	10,12	21,40	0
20	2	5	2	17	11	7,40	7,25	13,09	1,41	15	10,12	21,40	0
21	4	3	7	10	8	6,40	7,25	13,09	1,41	7	10,12	21,40	0
22	4	4	8	5	8	5,80	7,25	13,09	1,41	4	10,12	21,40	0
23	6	2	8	4	8	5,60	7,25	13,09	1,41	6	10,12	21,40	0
24	4	9	8	3	8	6,40	7,25	13,09	1,41	6	10,12	21,40	0
25	5	9	10	4	8	7,20	7,25	13,09	1,41	6	10,12	21,40	0

Appendix C. Container Temperature (5 observations of the same profile on different days with 25 Billets at each observation)

Number of Billets	Observations					Average Data				Amplitude Data			
	1	2	3	4	5	\bar{x}	LC	LCS	LCI	R	LC	LCS	LCI
1	431,5	429,5	425,0	421,0	422,5	425,90	424,28	427,92	420,63	10,5	6,32	13,36	0
2	431,0	430,0	425,5	420,0	421,5	425,60	424,28	427,92	420,63	11	6,32	13,36	0
3	430,5	431,0	425,5	420,5	422,5	426,00	424,28	427,92	420,63	10,5	6,32	13,36	0
4	430,0	432,0	425,0	422,5	422,5	426,40	424,28	427,92	420,63	9,5	6,32	13,36	0
5	429,5	432,0	425,0	422,5	423,5	426,50	424,28	427,92	420,63	9,5	6,32	13,36	0
6	428,5	431,5	424,5	422,0	424,5	426,20	424,28	427,92	420,63	9,5	6,32	13,36	0
7	428,0	431,0	424,5	421,5	424,5	425,90	424,28	427,92	420,63	9,5	6,32	13,36	0
8	427,0	430,0	423,5	422,5	425,5	425,70	424,28	427,92	420,63	7,5	6,32	13,36	0
9	426,5	428,5	423,5	422,5	426,0	425,40	424,28	427,92	420,63	6	6,32	13,36	0
10	425,5	427,5	424,5	422,0	426,0	425,10	424,28	427,92	420,63	5,5	6,32	13,36	0
11	425,0	426,5	424,0	422,5	425,5	424,70	424,28	427,92	420,63	4	6,32	13,36	0
12	424,5	425,5	416,5	422,0	425,0	422,70	424,28	427,92	420,63	9	6,32	13,36	0
13	423,5	425,0	418,5	422,5	425,0	422,90	424,28	427,92	420,63	6,5	6,32	13,36	0
14	422,5	424,5	420,5	422,5	424,5	422,90	424,28	427,92	420,63	4	6,32	13,36	0
15	422,0	424,0	422,0	422,5	424,5	423,00	424,28	427,92	420,63	2,5	6,32	13,36	0
16	421,0	423,0	421,0	422,0	424,0	422,20	424,28	427,92	420,63	3	6,32	13,36	0
17	421,0	425,0	421,5	422,5	424,0	422,80	424,28	427,92	420,63	4	6,32	13,36	0
18	421,5	424,5	422,0	422,0	423,5	422,70	424,28	427,92	420,63	3	6,32	13,36	0
19	422,5	425,0	422,0	421,5	423,0	422,80	424,28	427,92	420,63	3,5	6,32	13,36	0
20	423,5	425,0	422,0	422,0	423,5	423,20	424,28	427,92	420,63	3	6,32	13,36	0
21	424,5	425,0	421,5	422,5	424,0	423,50	424,28	427,92	420,63	3,5	6,32	13,36	0
22	425,5	424,5	422,0	422,0	423,5	423,50	424,28	427,92	420,63	3,5	6,32	13,36	0
23	426,5	425,0	421,0	422,5	423,0	423,60	424,28	427,92	420,63	5,5	6,32	13,36	0
24	427,5	425,0	421,0	422,0	423,5	423,80	424,28	427,92	420,63	6,5	6,32	13,36	0
25	428,5	424,5	421,0	422,0	423,5	423,90	424,28	427,92	420,63	7,5	6,32	13,36	0

