Control of Nonconformities Using Quality Tools in an Aluminum Extrusion Industry

Fátima De Almeida, Aldina Correia and Nuno Carvalho

***Abstract*—**Aluminum alloys have great potential, capturing the interest of industry and researchers. The productivity, cost and quality of the extruded profiles are the main factors of industrial interest. Among the various steps of the production of aluminum from metal, a lot of scrap is generated due to the machining operations. During the aluminium extrusion, defects are largely responsible for decreasing the quality of the finished product because they lead to increased production costs, delays in delivery and increase of the scrap percentage.

In this work we applied quality tools, in particular some classical Statistical Process Control tools in order to monitoring nonconformities and minimize the percentage of scrap produced in an aluminum extrusion industry.

***Keywords*—** Aluminum industry, extrusion, surface defects, product quality.

I. Introduction

CORRENTLY alloy profile has plenty of applications in many fields, such as structures used in aviation, aerospace, traffic transportation, civil architecture and among others; due to its advantages in light-weight, less exhaust emissions, high surface quality, and easy recycling [1-6]

Aluminum profile extrusion process is a common and useful process to produce extrudate with complex section shape or thin-wall [2-3]. The aluminum industry and the extrusion industry have progressed from operating locally to operating as a global industry with increasing competition from other materials and increasing demands on the quality and price [7].

The product cost, time-to-market, and product quality are three key factors which determine the competitiveness of the developed products [8].

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.

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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. The concept of quality, consumer oriented, should be the starting point for an organization that wants continuous quality improvement [9].

The quality of extruded product depends on many technological factors and the proper die design [4, 8]. Otherwise, the extrusion conditions variations might cause disparities in the properties and several defects in the final product, which affects the productivity of the extrusion process.

As notice Lesniak and Libura [10], an optimal pocket die geometry leading to the best surface quality of the product can be found from the criterion of the volume rate control. Based on the billet track analysis, Chen [11] found that the effect of ram velocity on the appearance of back end defect is slight. Bastania [12], through the curves for isothermal conditions, indicates that container cooling can allow the extruder to operate at a higher rate of productivity while maintaining isothermal conditions. For a given die and section, these variations can be repeated during the numerous press cycles increasing the nonconformity products.

During the extrusion process, combating waste is a goal to be achieved [13]. One way to identify waste is to keep the process under control, and to control it, you need to know the whole process. Since "keeping under control is knowing how to locate the problem, analyse the process, standardize and establish control items in such a way that the problem never happens again" [14]. This is the only way to increase productivity, because "to produce more and more and/or better with less and less" [14].

In this way, the reduction of the level of quality defects and the manufacture of high quality products do not result from the inspection activities but fundamentally from the improvement activities process, making them more efficient, simpler, safer and, fundamentally, with less nonconformities, minimizing the quantity of scrap [15].

Quality defined through the level of consumer satisfaction (products according to specifications, or quality such as absence of defects (fewer defects = less costs) [16]. In order to meet the customer's needs, and to guarantee the delivery of the product according to its requirements, it is necessary to find solutions that allow the collection of information, along the entire production chain, and their analysis and use to a better decision-making. This can help companies to improve their operational efficiency and overall the quality of the product. Of the many Process Control (PC) tools available to ensure better quality control and optimum quality, Statistical Process Control (SPC) allows to optimize and monitor quality using the data created throughout the entire productive process.

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

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

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

Through the application of quality tools, it is intended to contribute to the reduction of the variability of processes and products quality and, consequently, to reduce production costs. In the particular case of the aluminium extrusion industry, whose waste/scrap represents significant costs for the company, it was considered appropriate to implement a program to improve the quality of the process, based on the following objectives:

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

In a previous work [17], resorting data previously collected in an industry in this area, concerning with eight months of production, we classified and quantified the defects that occur throughout the extrusion process. To identify the causes, correct possible deviations and explore possible solutions and improvements, several quality tools in particular: Brainstorming, Pareto Diagram, Ishikawa Diagram, Histogram and Control Chart, are used. 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. In this work, 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. Followed by the defect Scratches/Damages, which corresponds to around 35% of the total.

In this work, we intend to study this second main defect, using quality control tools, in the same company of aluminum extrusion, considering data collected in an extended period of fourteen months of production. It is also a goal to compare the behavior of the quantities/percentages of scrap production in order to prevent their increase. For that we consider six parts. The first is this introduction, in the second part we present some considerations of the classical quality tools used in industry, and in particular in [17]. The third part is the company ADLA presentation and the summary of the productive process under study. The procedure for data collection and the methodology presentation is in section four. The results obtained are presented in the section five and the paper ends with conclusions and future lines of investigation.

II. Quality Tools

The issue of how to improve product quality and product yield in a brief period of time becomes more critical in many industries [13]. 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 [14].

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 [15]. According to Professor Ishikawa, 95% of a company's problems can be solved with the basic quality tools, and the key to problem solving lies in the ability to identify the problem and to use the appropriate tools, based on the nature of the problem and quickly communicate the solution to others [9]. Their consist of simple means for problem solving and can be used by all employees, promoting teamwork, since their visualization allows the understanding of all. Although there are a great variety of quality tools, the most important are the seven basic quality tools, suggested by Ishikawa, namely [18]: Cause and effect diagrams; Pareto Charts; Check sheets; Flowcharts; Histograms; Scatter plots and 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 Statistical Process Control (SPC) [16]. SPC provides use of the statistical principles and techniques at every stage of the production and aims to control quality characteristics on the methods, machine, products, equipments both for the company and operators [19]. 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 [17]. 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. 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. The SPC allows us to know if the process is working correctly or not [16].

III. Company ADLA and Productive Process

A. Company

ADLA Aluminum Extrusion S. A., is a young company (constituted in 2011) dedicated and specialized in the development and production of aluminum profiles. It is a national company, which manufactures aluminum 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 Aluminum Extrusion S. A. has as its mission:

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

B. Aluminum Extrusion Process

The production process in the Company ADLA Aluminium Extrusion S. A. is divided into four parts: aluminum extrusion, stretching, cutting and heat treatment combined by small processes, as illustrated with figures and more detailed explanations in [17].

Firstly, aluminum billets are stored in batches, according to the alloy and the supplier. 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 and the process starts with a simple cleaning of the surface, to remove dirt and some surface impurities that may exist.

In a second step, the billets enter the preheating furnace where they are heated in a most homogeneous way. This gas-fired oven consists of five heating zones allowing gradual heating and avoiding that the billet is exposed to high temperatures for an extended period of time, and, on the other hand, to thermal gradients (temperature differences throughout the billet).

After the production planning, the production system starts the extrusion process of the profiles. The extrusion is prepared by heating the billet according to the specified alloy and the dies already prepared. At the exit from the oven the billets are cut and transported 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.

When coming out the press the profiles are inspected visually, the production control register is completed and if they meet the specifications the production order continues. Otherwise, they are rejected, the nonconformity is recorded and forwarded to the quality department.

In the same production series, the profiles are extruded continuously, being cut with hot saw 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, 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, the bars are cut into bars of lower length and placed in containers which are transported to the aging furnaces, if the profiles are aged, or for shipment.

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.

C. Nonconformities

As already mentioned, extrusion is a process with several parameters that 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 literature, it was evident a strong relationship of dependency between the different variables. During the extrusion process of aluminum alloy, the ram velocity should be well controlled, since it is an important parameter affecting the profile quality and extrusion productivity [11].

The influence of extrusion conditions on the internal structure and mechanical properties of extruded AZ31B magnesium alloy profiles were analyzed [20]. Two main conclusions the authors point out:

1. as extrusion ratio increases, elongation of the extrusion also increases due to grain refining;
2. when billet temperature is lower and extrusion speed is smaller, grain size of the extrusion decreases.

Additionally, in most cold rolling processes, there is some rough contact between the tool and the workpiece surfaces. This requires a compromise between reasonable levels of friction and good surface finish [21]. Otherwise, microcracks are formed in the oxide film near the entrance of the bite roller.

The quality of the final product is affected by the interaction between the variables, resulting in different material characteristics. Thus, 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 [22].

However, the quality of any extruded product is a function of various factors, such as chemical composition, geometric dimensions, appearance and regularity of the microstructure, variation of mechanical properties over the extruded length and cross section, and surface finish [19, 22]. An extruded profile may be deemed, to be a rejected, following these four reasons: defective billets; faulty or unsuitable tooling; defects arising during extrusion; and, flaws resulting in the course of post-extrusion operations [22].

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.

Thus, product rejection can be traced to material defects, tool defects, processing anomalies, and post-extrusion defects and surface finishing [23].

Some extrusion is a process with many variables which can be controlled by the operator as billet temperature, extrusion speed, billet length, while others cannot as exit temperature, for example.

It now well recognized that the structure of material requires careful control and hence integrated process must be considered.

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.

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.

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

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

IV. Data Collection and Methodology

In a previous work [14], we used the analysis of several data sources, namely, company documents and fact sheets during eight months of production (between January and August, 2017). In this work we considered similar data, concerning with ADLA Aluminum Extrusion S. A., but a different period of time production, expanding the data range from eight to fourteen months (from January 2017 to February 2018). A diagnosis was made, trying to observe possible variations of the extrusion parameters during the last productions. It was conclude, in [17] and also in [24], that some extrusion conditions are crucial, to minimize/maximize the percentage of scrap produced, in the aluminium extrusion process, using for example, SPC and other quality tools, because is crucial continue to monitor the process, which is what is done in this work.Thus multiple quality tools were used: Check sheets, in order to identify the types of NC which contributes for the increase of the percentage of scrap; Pareto diagrams to identify the major cause of defect rejection; (nonconformities) and Cause and effect Ishikawa diagram to identify and structure the possible causes that give rise to the defects Scratches/Damages, the second main type of defects observed in ADLA Aluminum Extrusion S. A..

II. Data Analysis and results

A. Checklist

In an initial phase in [17], an evaluation of the types of NC with higher occurrence was carried out, using check sheets, and a data collection with eight months of production, between January and August, 2017 (data presented summary in table 1).

Table 1 – Checklist for the types of NC, observed in ADLA, between January and August, 2017 [17]

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		

It can be seen in table 1 that the "Blisters" defect represents around 38% of the defects recorded in the productions of the period under analysis in ADLA Aluminum Extrusion S. A., followed by the defect Scratches/Damages, which corresponds to around 35% of the total produced. Both defects type together represent 72% of the scrap production been the main reasons for the company's profit loss.

Having into account the new ADLA Aluminum Extrusion S.A.

data, expanding the data range from eight to fourteen months (from January 2017 to February 2018) the scenario is not very different (data presented summary in table 2) reinforcing the importance also of the study of causes of the defects Scratches/Damages, the second main type of defects observed in ADLA Aluminum Extrusion S. A..

Table 2 – Checklist for the types of NC, observed in ADLA, January 2017 to February 2018

Type of defects	Total	Accumulated value (€)	Accumulated %
Blisters	27520,73	27520,73	42,06%
Scratches/Damages	20229,13	47749,86	72,97%
Lines	4646,40	52396,26	80,07%
Out of Angle	4568,93	56965,19	87,06%
Wrinkle	3361,36	60326,54	92,19%
Concavity	1546,42	61872,96	94,56%
Hole B.	1489,01	63361,97	96,83%
Rough Surf	1086,25	64448,22	98,49%
Twist/Bends	551,42	64999,64	99,33%
Convexity	435,84	65435,48	100,00%
Total	65435.48		

It can be seen in table 2 that the "Blisters" and “Scratches/Damages” defects continue to represent the main reasons for the company's profit loss. Around 42% of the defects recorded in the productions of the new period under analysis in ADLA Aluminum Extrusion S. A., are "Blisters" and around 31% are “Scratches/Damages”.

B. Pareto Diagram

Based on the information extracted from the Check Sheet the Pareto Diagram (Fig. 1) 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 around 42% of the NC, is the most representative failure found during the process.

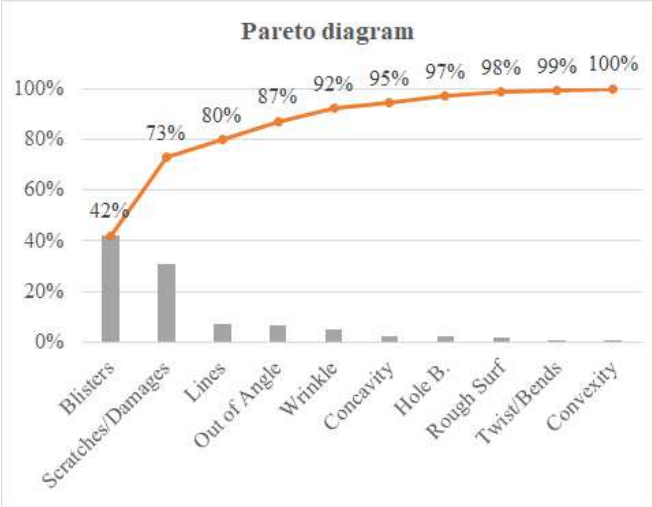

Fig. 1 – Pareto diagram for NC in ADLA, January 2017 to February 2018

In [1], based on the classification of the “Blisters”, 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.
Now, in Fig. 2, is presented a similar Diagram or Cause and Effect Diagram to explore the second main cause of non-compliance: Scratches/Damages. It shows the main causes and contributions, in different stages of the extrusion process, for one of the main defects identified in the produced profiles.
Indeed, the defect studied in [1] “Blisters” is the main cause of scrap production, but the second type of defect “Scratches/Damages” is also a very relevant defect and plays a fundamental role in the amount of scrap produced.
The cause-and-effect diagram can aid in identifying reasons, as well as it can provide guidance on causes to be investigated for process improvement.

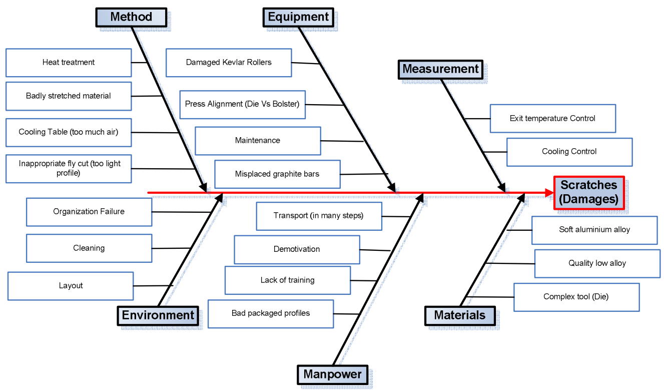

Fig. 2 – Cause and Effect Diagram NC “Scratches/Damages”

During the extrusion process there are several variables that directly affect the quality of the extruded profiles. After analyzing the causes that most affect the appearance of the "Scratches/Damages" defect, the target variables of study/control are:

- Exit temperature control
- Cooling control

The cause-and-effect diagrams for Scratches/Damages defect products developed, shows how defects at different stages contribute to the final quality of a aluminium profile.

A large number of contributions were identified in the causes and effect diagram. However, for the class manpower, environment, method and equipment, some contributions as transportation, overweight, conditioning and stretching of the material, as well as lack of care when cutting, were identified. These irregularities, which cause the non-conformities of the aluminium profiles produced by Scratches/Damages, could be controlled through worker training.

Finally, some real picture, captured in ADLA company of the scratches/damages, are presented in Fig. 3.

Fig. 3. Scratches/Damages defect.

V. Conclusion and Future work

Most of the metallurgical defects in ADLA aluminum extrusion can be divided into two major categories: Blisters and Scratches/Damages. However, a conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Acknowledgment

Our thanks to ADLA Aluminum Extrusion S. A. company for the data and images provided, which enabled us to prepare this document.

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