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EVALUATION OF HOT ROLLING PARAMETERS IN THE METAL YIELD INDICATOR FOR THE PRODUCTION OF SEAMLESS STEEL TUBES

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ABSTRACT

In order to become or remain competitive in the face of the current competition, companies have used statistical techniques, such as the factorial experiment, that allow us to evaluate productive processes in order to improve them, thus reducing the possibility of failure. The purpose of this paper is to present an application of the statistical technique, Full Factorial Experiment 2^K, in a process of production of seamless steel tubes, with the objective of studying the specificities of the main metal yield indicator, called VZ (Verbrauch Zieff), which describes the income from the use of inputs on the production of pipes. Four factors were defined for the analysis: steel type, gauge, lamination wall and heat treatment. For the accomplishment of the present study, the adopted methodology is the research of empirical and descriptive nature, through a combined, qualitative and quantitative approach. The performance of the factorial experiment using the chosen factors resulted in a view previously unknown by the company of how the factors and their interactions influence the indicator studied, the type factors of steel and gauge being statistically significant, generating greater assertiveness in the planning of raw material and thus reducing the general costs of the products.

Keywords: Factorial Experiment; Lamination; Metallic Yield.

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1. INTRODUCTION

Steel production is growing every year and by 2014 world production was 1.66 billion tons, which represents an increase of 1.2% compared to 2013. The largest steel producers that year were China, Japan, the Middle East and the United States (Worldsteel, 2015). According to the Brazilian Steel Institute, IAB (2015), the Brazilian steel industry is represented by fourteen private companies, making Brazil the largest steel industrial park in South America today, occupying the ninth position in the world steel production ranking in 2014. However, the industry currently experiences a slowdown in the domestic demand for steel products and operates with idleness in relation to installed capacity in the country, with some companies operating at about 50% of their capacity. The contraction of the domestic market and the deceleration of the economy were accentuated by the increased competition of imported steel and by the weak performance of the Brazilian economy, which in 2014 represented an 8.6% reduction in apparent consumption compared to 2013 (IAB, 2015). Faced with this challenging scenario, cost management must be improved so that the company can survive today.

In 2016, a survey was carried out by the Controllership, where the metallic income indicator called VZ (Verbraucht Ziffer) showed a potential cost reduction of 23.5% (internal data of the company under study) at the production stage of the lamination, justifying the present study. The VZ indicator is calculated as the ratio between the amount of raw material consumed and quantity produced within the process. After the study, it was possible to plan with greater assertiveness the amount of raw material to be used. This allowed reducing the general costs of the products, the real occupation of the production line, with reduction of wastes, besides being able to systematically follow the evolution of the indicator, in order to make decisions that generate gains for the sector studied, thus pointing out its relevance.

The company, which is the focus of this work, is located in Alto Paraopeba, Minas Gerais, and manufactures seamless steel pipes for domestic and export markets, mainly for the oil and gas sectors. The present study aims to evaluate the productive parameters of hot rolling, according to the influence of these parameters on the productivity of the process, using the statistical tool Factorial Experiment, known in the literature as part of the DOE (Design of Experiments, or Planning and Analysis of Experiments). This technique is a great ally, because through it, one can analyze the variables involved in the behavior of the process performance indicator and its interactions, as well as propose solutions that allow a complete optimization of the process and its variables through the factorial experiment, and without the initial need for large investments.

2. THE STATISTICAL TECHNIQUE OF PLANNING AND ANALYSIS OF EXPERIMENTS

With the increase of competitiveness, the need for optimization of products and processes whose objective is the reduction of costs and times was also increased. This motivates the search for systematic statistical planning techniques. The methodology used in the DOE is based on statistical theory and can be used both in the development of the process and in solving problems to improve its performance or to obtain a process that is robust or not sensitive to external sources of variability (Salles *et al*., 2010).

According to Galdámez (2002), DOE is a technique used to plan experiments in order to obtain operational excellence that allows for more reliable results and can be applied in different sectors and problems. Santos (2017) applied the DOE to improve the service level of data file processing for web page hosting, achieving lower consumption of RAM and CPU cores. Another area where the use of DOE can be observed can be exemplified by the recent work of Hazir et al. (2018). The authors applied the complete 2^k factorial planning technique, analyzing five machining factors for the optimization of cutting parameters of a CNC machine, and were able to reach the goal, that is, to obtain a minimum value of surface roughness in wood.

Experiments are performed with the objective of knowing a particular system and comparing the effects caused by several factors involved in it through a series of tests, where changes are made to the system input variables. This allows verifying the effects of the response variables, so that the variability of this response is minimal due to the effect of the uncontrollable variables (noise) of the studied system (Montgomery *et* Runger, 2012).

Costa (2011) and Button (2012) state that the main advantages of the planned experiments are: with a small number of tests, a high quality of information is obtained; it allows the experimenter to optimize a response variable; an experimental error can be calculated in order to verify to what level one can rely on the result obtained; improvement in production; reduced variability and conformity closer to nominal; evaluation of alternative materials; determination of the key parameters of product planning; improvement in process efficiency and reduction of times; reduction of operating costs and total costs; reduction of time and process variation; and improving the quality of the information obtained from the results.

According to Montgomery and Runger (2012), the main terminologies of the experiments are:

- Variable response: it is the dependent variable that during an experiment undergoes some type of effect caused by factors;

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- Factors (x): are factors purposely altered in the experiment to evaluate the effect produced in the response variable and, with this, to be able to determine the main factors;

- Levels (n): These are the different groups to be compared. They can take quantitative or qualitative values. They are the operating conditions of the control factors investigated in the experiments. When you have two levels, these are usually identified by low level (-1) and high level (+1);

- Treatments: these are the specific combinations of levels of control factors in the experiment, that is, each round will be a different treatment;

- Effect (α): Defined as the change in response when moving a factor from low level (-) to high level (+);

- Main effect: it is the average difference observed in the response when changing the level of the control factor investigated;

- Interaction effect: it is half the difference between the main effects of a factor on the levels of another factor. The interaction values between the factors can be calculated taking into account the signals already assigned to the variables involved, as if it were a mathematical multiplication operation;

- Interactions: through mutual influence, two or more factors involved in the experiment become statistically significant;

- Noise: they are variables that can influence the response variable defined in the experiment, which can be controlled or not;

- Randomization: it is the practice of choosing races (or experimental points) through a random process, which in many cases guarantees the identity and independence conditions of the collected data and avoids systematic errors;

- Blocks: It is the technique used to control and evaluate the variability produced by the disturbing factors (controllable or non-controllable that are not of interest) of the experiments through data groupings. With this technique, it is sought to create a more homogeneous experiment and increase the accuracy of the answers that are analyzed;

- Repetition: is the process of repeating each of the combinations (lines) of the experimental matrix under the same experimental conditions. This concept allows finding an estimate of the experimental error, which is used to determine whether the observed differences between the data are statistically significant and allows estimating the effects of a factor when the average of a result is used.

According to Werkema et Aguiar (1996), the planning of experiments can be classified into several types: Full factorial; Factorial 2^k complete; Factorial in blocks; Fractional factorial; Randomized blocks; Incomplete blocks balanced; Partially balanced incomplete blocks; Latin squares; Youden squares; Hierarchical; Response Surface; Completely randomized with a single factor, among others.

Among the experimental planning methods available in the literature, Full Factorial Planning is the most appropriate when it is desired to study the effects of two or more influence variables, and in each attempt or replica, all possible combinations of the levels of each variable are investigated (Button, 2012).

In this work, the Factorial Full 2^k Planning will be approached, because factors will be investigated, analyzed in two levels, high and low. This type of planning is particularly useful in the early stages of an experimental work when one has many variables to investigate. This procedure provides the least number of runs with which k factors can be studied in a complete factorial planning. Consequently, these schedules are widely used in factor sweep experiments (Calado *et* Montgomery, 2003).

3. STUDY METHODOLOGY

According to Gil (2002), research is a process of development of the scientific method in a formal and systematic way, whose main objective is to provide answers to the problems proposed through the use of scientific procedures, and can be classified into three main groups: exploratory, descriptive and explanatory. Therefore, the study in question can be classified as descriptive as to its objective, that is, the research observes, registers, analyzes, and correlates facts or phenomena (variables).

In addition, the research will be applied, as it will involve practices and studies that will contribute to the identification of the problem raised from the study data, in order to reach real applications. As for the means, the research is experimental and uses the statistical technique of Full Factorial Experiment, which is a very effective tool to study complex systems, since it allows identifying the interactions among the variables involved in the problem, as in each attempt or replica of the experiment, all possible combinations of factor levels are investigated.

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The authors Montgomery et Runger (2012), Galdámez (2002), Rodrigues et Iemma (2005) and Salles et al. (2010) recommend that during the experimentation process a strategic plan be made to coordinate activities. Next, the activities of the experimental procedure are presented, according to these authors, who will be part of the methodological approach developed for the conduction of the present study.

3.1 Defining the objectives of the experiment

It is necessary to define the problems, the objectives of the experiment and, mainly, to define who will participate in the activities of the experimental process. According to Werkema et Aguiar (1996) those involved must know the importance of correctly analyzing the factors that influence the defined problem. Montgomery et Runger (2012) suggest that brainstorming be used to obtain relevant information. According to Caten et Ribeiro (1996), the objectives should be specific, measurable, non-biased and should have practical consequences.

3.2 Parameters of the experiment

It involves collecting technical information, in which people must list all control factors, noise factors, adjustment levels, and response variables. At this stage, technical information can result from a combination of experience and theoretical understanding.

3.3 Selection of control factors and response variables

Select the control factors (independent variables), the ranges of variation of the levels of these factors and the responses of the experiment (dependent variables), as well as to define the method of measurement of the control factors.

3.4 Selection of the experimental matrix

Select or construct the experimental matrix considering the number of control factors, the number of levels and the non-controllable factors of the process. In addition, it is necessary to define the sequences of the races at random, the number of replicates, the restrictions of the experiments and the possible interactions that may occur between the factors being evaluated.

3.5 Conducting the experiment

According to Bracarense (2012), the choice of planning involves consideration of sample size (number of replications), selection of an appropriate order of rounds for experimental trials, and whether block formation or other randomization constraints are involved. While it is conducted, the experiment must be monitored to ensure correct compliance with the plan and to record any changes that occurred during the execution. Reporting is recommended at the end of the experiment because the information contained can enrich the results obtained by the data analysis and validate if the experiments were correctly performed. Errors in the experimental procedure at this stage will generally destroy the validity of the experiment.

3.6 Data analysis

According to Montgomery et Runger (2012) and Werkema et Aguiar (1996), statistical methods should be used to analyze the data, so that the results and conclusions are objective, not an opinion. Statistical software (Minitab, Action, Anova, among others) can be used to aid in the generation of information. Statistical concepts are applied in the results of an experiment to describe the behavior of control variables and the relationship between them and to estimate the effects produced on the observed responses. It also allows you to decide when to accept or reject the hypotheses formulated previously.

3.7 Interpretation of results

Extraction of the practical conclusions of the results from graphs and worksheets and recommendation of actions of improvements.

3.8 Report elaboration

In the final report, one must identify the theoretical and practical limitations found, the recommendations for future experiments and the conclusions obtained, since this feedback can be of great benefit to the process of evaluating the performance of industrial experiments.

4. THE COMPANY STUDIED

The company studied, Vallourec Soluções Tubulares do Brasil S.A., or simply VSB, is a joint venture with installed capacity of 600kt/year, located in Jeceaba, Minas Gerais. It produces seamless steel tubes for drilling, well casing and oil and gas pipelines, both domestically and externally, mainly in the oil sector. It consolidates its position in the market, mainly due to the high quality index of its final product, according to certifications already in place in the company, such as ISO Q1, API 5CT, API 5L, ISO 9001: 2008 and ISO

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17025. It is an integrated plant that counts on sectors such as Pelletizing, Blast Furnace, Steelworks, Lamination, Thermal Treatment, and Finishing Lines.

4.1. Factors and levels

Brainstorming was performed with the technical staff of the lamination process, defining the factors (independent variables) that possibly impact the indicator under study (dependent variable). They are: steel, gauge, rolling wall and the type of heat treatment. These variables were classified into two qualitative levels, high and low, according to the appropriate description of each factor, described in the following subsections.

During the rolling process, all finished production order data are recorded through production management software and later the official production reports are made available for analysis and decision making. For this study, the raw data were collected from the system from January 2014 to December 2015, and then processed in order to obtain the VZ of each production order according to the chosen variables.

4.1.1. Type of Steel

Tubes produced from Lipe Pine (LP) steels are tubes designed for conduction in various segments, such as pipelines. The OCTG (Oil Country Tubes Goods) type pipes are intended for drilling. In Figure 1 it is possible to verify the behavior of the VZ indicator for all types of steels already produced and the variation of this indicator when compared between them. In Figure 2, it can be observed that, when the steels were aggregated, the values obtained presented a certain variation, and from this analysis, the high level (LP) and low level (OCTG) for the steel factor.

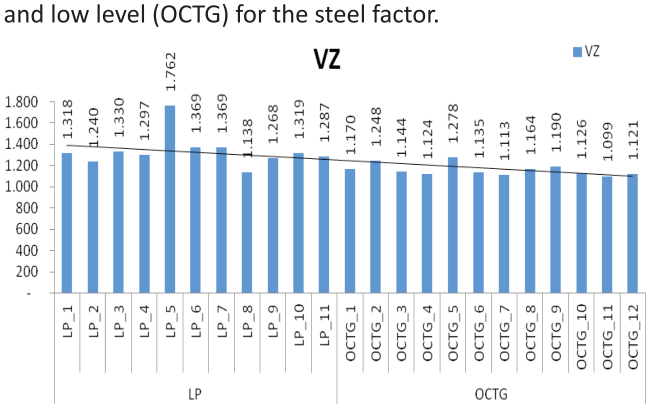

Figure 1. VZ of steels produced
Source: The authors themselves

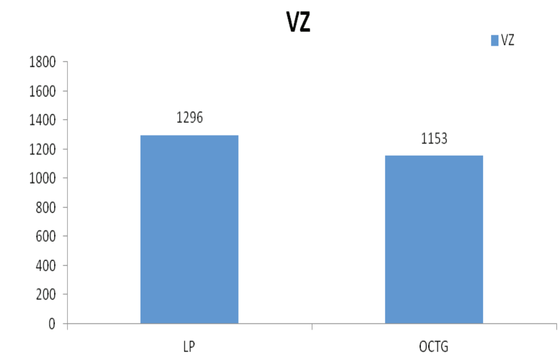

Figure 2. VZ of steels after setting levels
Source: The authors themselves

4.1.2. Caliber

It is defined as the diameter of the tube in the elongation mill, and the company has four defined gauges (in mm): 239, 296, 382, and 435. For the accomplishment of the factorial experiment, the gauges were segregated into 2 large groups: Caliber I (239 and 296mm) and Caliber II (382 and 435mm). In Figure 3 it is possible to verify the behavior of the VZ indicator for the different calibers and their variations, and in Figure 4 it is possible to observe that, when the calibers were aggregated, the values obtained presented a certain variation and, from that analysis, the high level (Caliber II) and low level (Caliber I) were qualitatively defined.

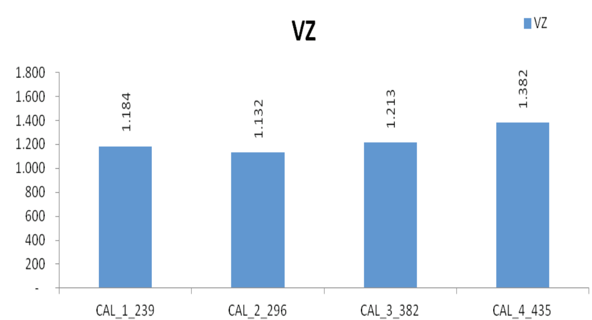

Figure 3. VZ for all calibers
Source: The authors themselves

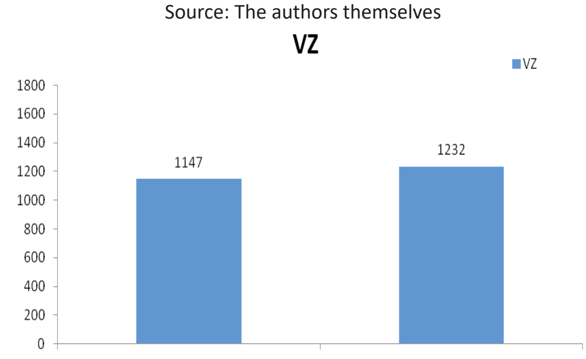

Figure 4. VZ per caliber after setting levels
Source: The authors themselves

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4.1.3. Laminate Wall

Due to the great variability of laminable walls, the materials were segregated into two large groups, Wall I and Wall II, with Wall I being between P01 and P35 (6.2 to 13.06 mm, including it) and Wall II comprised between P36 and P94 (13.07 to 35.5 mm, including it), according to company specifications. In Figure 5, it is possible to verify the behavior of the VZ indicator for all laminated walls in the selected period and the variation of this indicator when compared between them. In Figure 6 it can be observed that, when the walls were aggregated, the values obtained presented variation, and, from this analysis, the high level (Wall I) and the low level (Wall II).

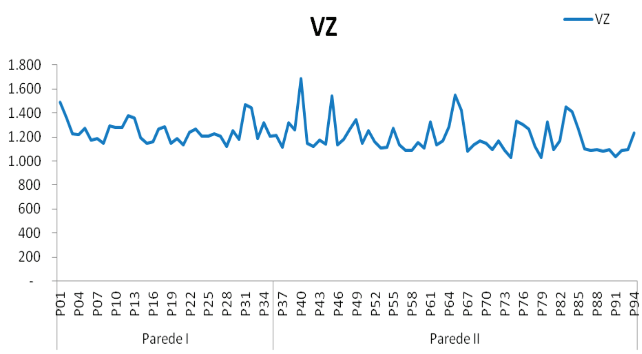

Figure 5. VZ for all walls

Source: the authors themselves

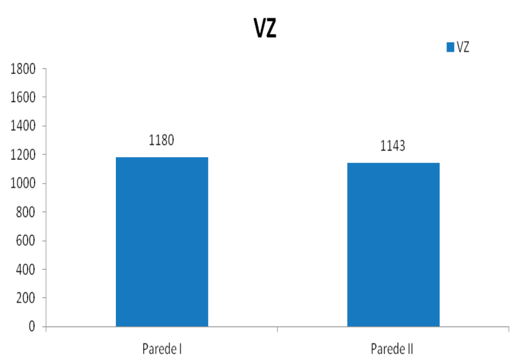

Figure 6. VZ per wall after setting levels

Source: the authors themselves

4.1.4. Heat treatment

The tubes produced by the company, whose route is the thermal treatment sector, can be tempered and normalized (QT); and those whose routes are the finishing lines may be non-tempered (NQT). In Figure 7 it is possible to verify the behavior of the VZ indicator for the types of routes and thermal treatments. From this analysis the high (NQT) and low (QT) levels were defined for the heat treatment factor.

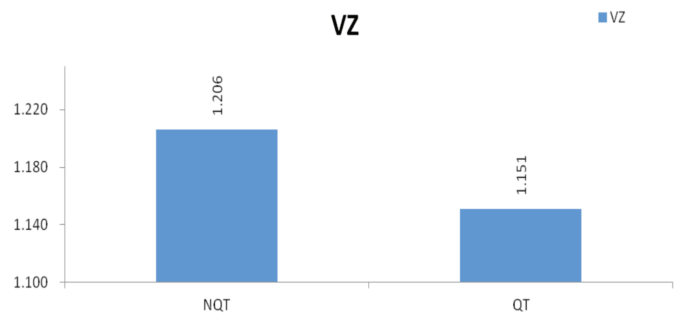

Figure 7. VZ for heat treatments

Source: the authors themselves

5. ANALYSIS OF THE COMPLETE FACTORIAL EXPERIMENT

After defining the 4 factors and their levels according to subitems above, the Full Factorial Experiment 2^k, without replicates, was applied, being $k = 4$, thus generating 16 treatments to be analyzed using the software Minitab®, granted by the company under study. Then, the analysis of the complete factorial experiment was performed applying the sparsity principle, considering the interactions and effects of second order, as shown in Figure 8.

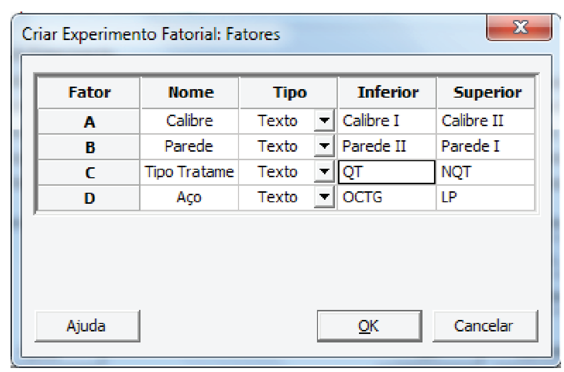

Figure 8. Creation of the experiment

Source: the authors themselves

Legend: from the top, of left to right

Create Factorial Experiment: Factors

Factor – Name – Type – Inferior – Superior; A - Caliber – Text - Caliber I - Caliber II; B – Wall - Text -Wall I - Wall II; C - Type of Treatment - Text - QT – NQT; D – Steel – Text - OCTG – LP

5.1. Principle of Sparsity

According to Montgomery and Runger (2012), as the number of factors increases in one experiment, the number of estimated effects also increases. In some situations, the principle of sparsity of effects applies, that is, the system is usually dominated by the main effects and interactions of

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low orders, where third order or more interactions are usually neglected. When the number of factors is moderately large, such as k≥4, it is a common practice to perform only one replica, and then combine the higher order interactions as error estimates.

5.2. Pareto Chart for Effects and Normal Graphics of Effects

The Pareto graph in Figure 9 shows the absolute value of the effects and shows a vertical reference line in the graph. Any effect that extends beyond this baseline is potentially important. This reference line is determined from a scale that depends on the existence of an error term. Factors A and B exceeded the baseline, meaning that these are the most significant factors. None of the other factors or interactions between them were statistically significant at the level of α=0.05.

The Normal Effects Chart, Figure 10, shows negative effects on the left side and positive effects on the right side of the reference line, which indicates where points would be expected to fall if all effects were zero, making it difficult to compare the magnitude between positive and negative effects. It is used to compare the relative magnitude and statistical significance of both the main effects and interactions. Points that do not fall close to the line usually signal significant effects. The graph of Figure 10 shows that the factors B and A, Steel and Caliber, respectively, exert, in this order, the most statistically significant effects on the VZ indicator.

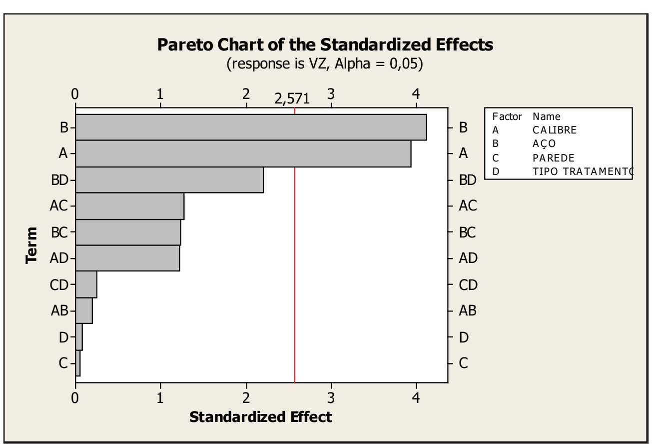

Figure 9. Normal Probability Chart of Effects

Source: the authors themselves

Legend: calibre = caliber; aço = steel; parede = wall; tipo de tratamento = type of treatment

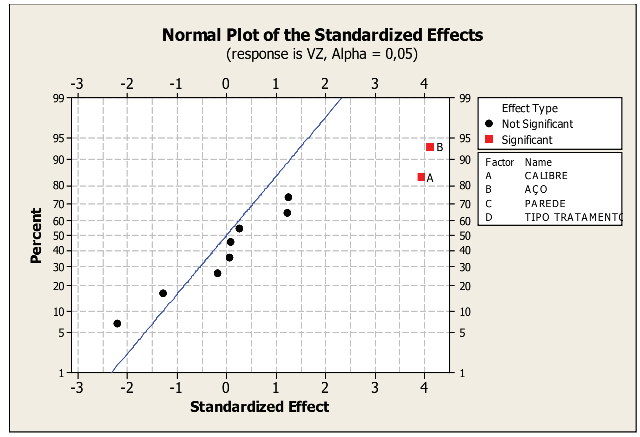

Figure 10. Normal Chart of Effects

Source: the authors themselves

5.3. Interaction between factors

When the lines shown in interaction graphs are parallel, or almost parallel, there are no interactions between the factors. Based on this, it is possible to notice, from Figure 11, that there is a certain interaction between the analyzed factors (except between the Caliber and Steel factors), meaning that the factors and their combinations have dependence, and that the effect caused by the level change of a factor in the response affects the level of another factor.

In practice, the factors have a certain interaction, since, based on the company's database, it can be noticed that Caliber I represented a larger volume produced against Caliber II, demonstrating that the knowledge and experience acquired impacts on a lower result for VZ, because the greater the experience, the smaller the errors that generate defects. Moreover, in Caliber I, OCTG steels represented 97% of the volume produced, contributing to the lower VZ, since, in practice, this type of steel is considered easy to laminate due to the existing alloying elements that generate fewer defects. In Caliber II, it can be observed that 78% of the volume produced refers to LP steels, which have a lower amount of alloys, making it difficult to laminate.

When the LP steels are analyzed, it is clear that they represent 14% of the volume produced against 86% of OCTG steels, reaffirming that the know-how has an impact on VZ. As it represents a smaller volume, smaller are the possibilities of failure correction during its manufacture and greater is the impact of the losses in their totality. In conjunction with the volume, it can be noted that 78% of the LP steels are applied to Caliber II, whose experience is still small due to its low production to date.

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Analyzing the Rolling Wall Factor, it is noted that 68% of the volume of LP steel produced is applied to thin-walled pipes whose VZ is larger. In practice, materials with thinner walls have a higher VZ, as defect generation occurs more easily due to the lamination process itself and its steps, such as transportation, heating, breakdown, and tools used. Regarding the type of treatment, it was possible to observe, through the analysis of the database, that QT type materials represent 60% of the volume produced, which generates more knowledge and use of best practices during its lamination. In addition, 48% of the volume produced is made in Caliber I, which has lower VZ due to the know-how acquired over the years and OCTG steels, which also have lower characteristic VZ.

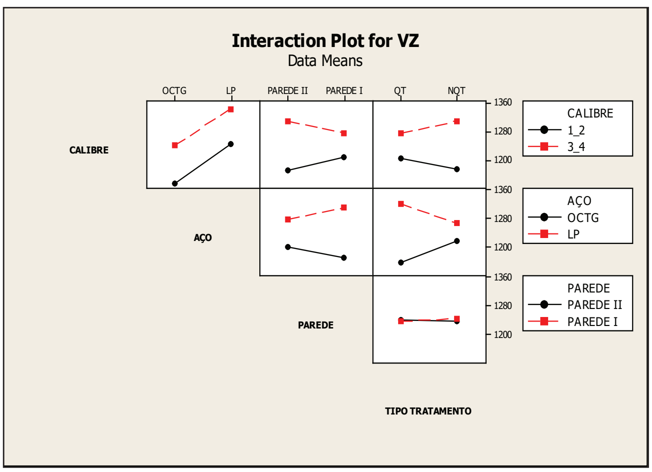

Figure 11. Interaction Graphs

Source: the authors themselves

Legend: calibre = caliber; aço = steel; parede = wall; tipo de tratamento = type of treatment

5.4. Evaluation of the main effects

The main effects graph is used to examine differences between the averages of levels for one or more factors. A major effect exists when different levels of a factor affect the response differently. It can be defined as the change occurring in the response when moving from the lowest (-) level to the highest (+) level of each factor studied, as illustrated by a line linking the mean of the response for each factor level.

From the Graphs of Main Effects of Figure 12, it is possible to notice that the Caliber and Steel factors presented greater main effect, since the line that connects the average answers for the low level and the high level has a steeper inclination compared to the other effects. The factors Wall and Type of Treatment were not significant, since the change from low to high was not statistically significant, as can be seen by the small inclination of the line joining the two levels.

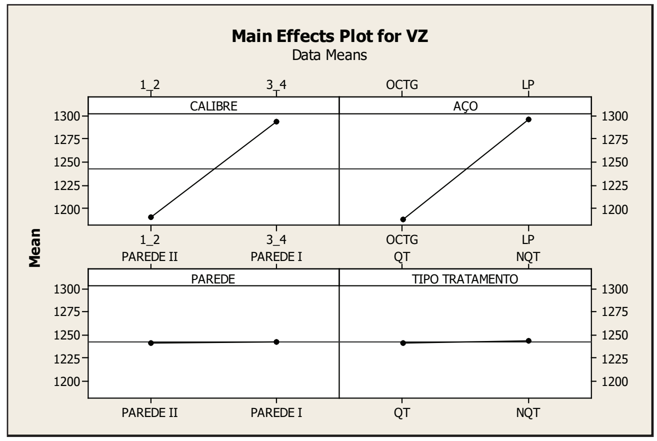

Figure 12. Full factorial experiment planning

Source: the authors themselves

Legend: calibre = caliber; aço = steel; parede = wall; tipo de tratamento = type of treatment

5.5. ANOVA table evaluation

From Table 1, column P (p-value), it is possible to prove that the Caliber and Steel factors are the most significant factors, since the assumed p-values are less than 0.05. On the other hand, the Wall and Type of Treatment factors presented p-value higher than 0.05, confirming analyzes shown in the main effects graphs. Analyzing the "Effect" column, it is possible to notice that the effects with greater significance are related to the Caliber and Steel factors, because the higher this value, the greater its effect on the response variable. The R-Sq value represents the proportion of variability in the response that is explained by the model, and the value obtained was 89.33%. Table 2 shows the analysis of variance of the experiment, where p-value analyzes can be performed to verify the significance of the main effects and other interactions.

5.6. Residues analysis

The residue histogram shows the distribution of residues for all observations. As can be seen in Figure 13, the data follow a normal distribution, which characterizes that there is no evidence of asymmetry or outliers. The Normal Probability graph for the residues shows the residues versus their expected values and those residues from the analysis, which were presented normally distributed.

For the Versus Fits x Fitted Value graph, Figure 13, the residuals must be, and are, distributed randomly around zero, characterizing that there is no evidence of non-constant variance, missing terms or outliers. The Versus Order x Observation Order chart graphically represents the residuals in the order of their corresponding observations. It is used

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to verify the influence of the collection of the orders or another factor in the result of the experiment. The data must present, and presented, a random pattern around the axis, characterizing that the error terms are correlated with each other.

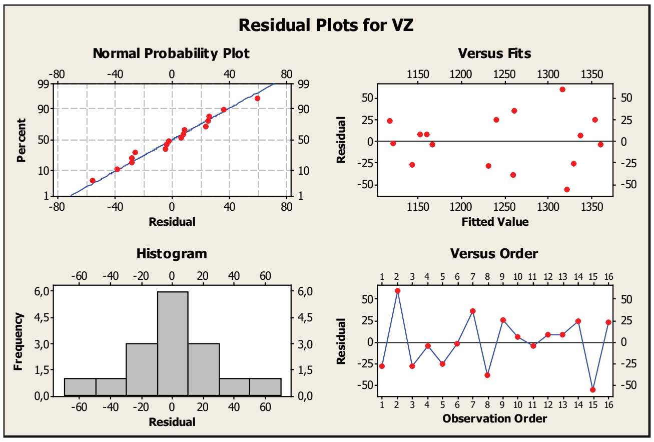

Figure 13. Generation of analyzed data

Source: the authors themselves

5.7. Equation of the model

The mathematical model using the factors chosen for the estimation of the yield indicator VZ obtained through the multiple linear regression equation is:

The variables *A* being the Caliber, *B* the Steel and *D* the Type of Treatment. These values assigned to the equation can be seen in the "Coef" column of Table 1. At the end of the expression there is the experimental error ε. The other data were not used because the interactions between the factors did not show statistical significance.

6. CONCLUSION OF THE EXPERIMENT

In many sectors of a company, it is often necessary to obtain product and process information empirically. Thus, it is necessary to design experiments, collect data and analyze them in a coherent way, in order to generate knowledge and actions. Based on this, one can note the importance of planning experiments in the engineering area, allowing more reliable results and conferring the process higher performances.

The main objective of this study was to evaluate the productive parameters of hot rolling from the application of Experimental Planning and Analysis (DOE) techniques, aiming to study the main indicator of metallic yield, VZ. Based on this, four parameters that influence VZ were studied and, in this way, it was possible to determine the effects that each factor exerts on the response variable, as well as to evaluate the interaction between the factors and how they affect the process and the result. These objectives were achieved, since the study was carried out with a relevant database, bringing to the fore relevant knowledge on the subject, in order to facilitate decision making, in addition to being consistent with the reality of the company. The experiment served reasonably well the conditions necessary for validation, even being in an industrial environment and having been made from a historical basis.

The conduction of the technique and analysis was carried out as planned, and the Expansion Principle was applied without violating the important conditions for the experiment. Thus, it was concluded that the statistically significant factors to be used for planning the VZ metal yield indicator, according to analyzes, were the Caliber and Type of Steel. For the Caliber factor, the result obtained in this experiment was consistent with practical rolling experience, since the production volume of the Caliber I level in relation to the

Table 1. Generation of the data analyzed for the effects

Factorial Fit: VZ versus CALIBRE; AÇO; PAREDE; TIPO TRATAMENTO

Estimated Effects and Coefficients for VZ (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		1242,23	13,16	94,42	0,000
CALIBRE	103,19	51,60	13,16	3,92	0,011
AÇO	108,21	54,11	13,16	4,11	0,009
PÁREDE	1,54	0,77	13,16	0,06	0,956
TIPO TRATAMENTO	2,17	1,09	13,16	0,08	0,937
CALIBRE*AÇO	-5,03	-2,51	13,16	-0,19	0,856
CALIBRE*PÁREDE	-33,46	-16,73	13,16	-1,27	0,259
CALIBRE*TIPO TRATAMENTO	32,17	16,08	13,16	1,22	0,276
AÇO*PAREDE	32,52	16,26	13,16	1,24	0,271
AÇO*TIPO TRATAMENTO	-57,85	-28,93	13,16	-2,20	0,079
PÁREDE*TIPO TRATAMENTO	6,63	3,31	13,16	0,25	0,811

S = 52,6230   PRESS = 141782
R-Sq = 89,33%   R-Sq(pred) = 0,00%   R-Sq(adj) = 68,00%

Table 2. Generation of analyzed data for variance

Analysis of Variance for VZ (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	89464	89464,2	22366,0	8,08	0,021
CALIBRE	1	42594	42594,1	42594,1	15,38	0,011
AÇO	1	46842	46841,8	46841,8	16,92	0,009
PÁREDE	1	9	9,5	9,5	0,00	0,956
TIPO TRATAMENTO	1	19	18,9	18,9	0,01	0,937
2-Way Interactions	6	26513	26513,0	4418,8	1,60	0,312
CALIBRE*AÇO	1	101	101,2	101,2	0,04	0,856
CALIBRE*PÁREDE	1	4479	4479,0	4479,0	1,62	0,259
CALIBRE*TIPO TRATAMENTO	1	4139	4138,8	4138,8	1,49	0,276
AÇO*PAREDE	1	4230	4229,7	4229,7	1,53	0,271
AÇO*TIPO TRATAMENTO	1	13389	13388,5	13388,5	4,83	0,079
PÁREDE*TIPO TRATAMENTO	1	176	175,8	175,8	0,06	0,811
Residual Error	5	13846	13845,9	2769,2		
Total	15	129823				

Unusual Observations for VZ

Legend: calibre = caliber; aço = steel; parede = wall; tipo de tratamento = type of treatment

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Caliber II level is relevant, generating greater know-how in the Caliber I. For the Type of steel factor, the result obtained was also consistent with the practical experience, since LP (Line Pipe) steels are of the type of greater productive complexity and, therefore, more subject to the generation of defects and consequent losses during rolling.

Wall factors and the type of treatment were not statistically significant. The Type of QT treatment level, despite having differences in the finishing line, was not relevant in relation to the Type of NQT treatment level. The Wall level I, despite presenting greater losses in the production process, in practice was not relevant in relation to the Wall II level. It is important to note that the analysis of the ANOVA table corroborated the graphically made analyzes.

The validity of the model used is verified through Analysis of Variance (ANOVA) and one way to verify if the adjusted model is adequate would be to look at the result of the coefficient of determination (R^2), which measures how much the response variable is explained by the model, because the higher the value of R^2 the better; and in the study carried out, R^2 was 89.33%.

A point of attention for conducting experiments, which induces barriers to the study, is about the strict control of the variables to be analyzed, reducing to the maximum the random error of variables not studied, since these can generate high variability that does not follow a normal distribution. A limitation of this study was the verification of special causes that impact the VZ, such as operational errors, successive breakdowns, lot size, among others. This is due to the difficulty of tracking and controlling all rolled orders during the selected period and during normal production. In addition, to perform the 2^K factorial experiment two levels per factor are required; thus, some factors, such as the caliber, have an influence on the response variable in a non-linear way, which can generate an error in the direct evaluation of this factor.

This was the first factorial experiment performed regarding the analysis of the main income indicator, VZ, and the independent factors adopted within the company under study, and the results obtained from the analyzes carried out indicated that the DOE application in the pipe production process was successful because it brought relevant knowledge. Finally, an extremely important result was to show the academic and business community the validity of scientifically and statistically analyzing a process and, with this, to encourage the use of these techniques with companies, since they allow evaluation of the process in order to improve it, thus reducing the possibility of failure. As the experiment, data processing and analyzes were performed, technical and practical information was acquired, as well as familiarization with the technique.

As future studies, it is suggested to carry out on-site production follow-up, in order to become aware of the special causes to treat them adequately, since the study was based on an extensive database (2 years) randomized, but without information on possible special causes. Moreover, as a suggestion, one can apply the approach proposed in other processes or sectors of the company studied, the use of new relevant productive parameters and with more recent data or analyzes with a factorial experiment with the response surface Rotary Compound Central Design (*Delineamento central composto rotacional* – DCCR) with which it will be possible to generate a greater level of detail, from variables considered important in this work.

REFERENCES

Bracarense, P. A. (2012), Estatística aplicada às ciências sociais, IESDE Brasil S.A, Curitiba, PR.

Button, S. T. (2012), Metodologia para planejamento experimental e análise de resultado, Universidade Estadual de Campinas, Campinas, SP.

Calado, V.; Montgomery, D. (2003), Planejamento de Experimentos usando o Statistica, 1. ed., E-papers, Rio de Janeiro, RJ.

Caten, C. S.; Ribeiro, J. L. D. (1996), "Etapas na Otimização Experimental de Produtos e Processos: Discussão e Estudo de Caso", Produção, Vol. 6, No. 1, Belo Horizonte, MG.

Costa, M. C. B. (2011), "A importância do ensino da ferramenta de planejamento fatorial para estudantes de engenharia", XXXIX Congresso Brasileiro de Educação em Engenharia, Blumenau, SC.

Galdámez, E. V. C. (2002), Aplicação das técnicas de planejamento e análise de experimentos na melhoria da qualidade de um processo de fabricação de produtos plásticos, Tese de Doutorado, Universidade de São Paulo, SP.

Gil, A. C. (2002), Projetos de pesquisa, 4. ed, Atlas, São Paulo.

Hazir, E.; Erdinler, E. S.; Koc, K. H. (2018), "Optimization of CNC cutting parameters using designs of experiments (DOE) and desirability function", Journal of Forestry Research, Vol. 29, No. 5, pp. 1423-1434.

Instituto Aço Brasil – IAB (2015), Números de mercado: Estatísticas, available from: http://www.acobrasil.org.br/site/portugues/numeros/estatisticas.asp (Access 24 Jun 2016).

Montgomery, D. C.; Runger, G. C. (2012), Probabilidade para engenheiros, 5. ed, LTC Editora, Rio de Janeiro, RJ.

Rodrigues, M. I.; Iemma, A. F. (2005), Planejamento de experimentos e otimização de processos: Uma estratégia sequencial de planejamentos, 1 ed., Casa do Pão Editora, Campinas, SP.

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Volume 11, Number 4, 2018, pp. 413-423
DOI: 10.20985/1980-5160.2018.v13n4.1216

Salles, C. A.; Silva, J. B. A.; Silva, R. B. (2010), "Planejamento e análise de experimentos para avaliação de resultados de ensaios mecânicos em blendas de polipropileno e polietileno de alta densidade", XXX ENEGEP, São Carlos, SP.

Santos, R. L. B. (2017), Análise de Dados e superfície de resposta: um estudo de caso para melhorar o desempenho de um serviço, Projeto Final (Bacharelado em Engenharia de Produção), Universidade Federal Fluminense, Niterói, RJ.

Werkema, M. C. C.; Aguiar, S. (1996), Planejamento e análise de experimentos: como identificar e avaliar as principais variáveis influentes em um processo, Fundação Christiano Ottoni, Escola de Engenharia da UFMG, Belo Horizonte, MG.

Worldsteel Association - World steel in figures 2015, available from: https://www.worldsteel.org/dms/internetDocumentList/bookshop/2015/World-Steel-in-Figures-2015/document/World%20Steel%20in%20Figures%202015.pdf (Access 24 de junho de 2016).

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