

Statistical Quality Control in MSMEs of Recycled Plastic Wood

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Abstract

The application of statistical quality control in plastic wood MSMEs in Ecuador is the first implementation carried out for this productive sector. Where the fundamental problem is the variation of the results of recycled plastic wood in tensile analysis, where the coefficient of variation is 51.38% with a maximum force of 605.42 N. In this case study, the methodology composed by the diagnosis Current of the production process, the identification of qualitative - quantitative variables and the implementation of statistical quality control. I provoke the standardization of the productive process in the criteria of selection of recycled plastics, optimum values of temperature, pressure and time in each of the subprocesses. Thus, improvements were obtained in the tensile analysis of recycled plastic wood where the coefficient of variation after the improvement is 7.26% with a maximum force of 751.03 N.

Keywords

Control, Quality, Variables, Control charts, Process cards,

1. Introduction

The use of plastic waste in Ecuador has grown in recent years, since the collection went from 60,870 to 182,857 tons / year according to the data of the Ministry of Environment. This means that it is collected or recycled three times more than the previous years, so it is currently considered an important commercial activity in the country (Poza 2019). This has as its edges the care of the environment, the extension of the life time of municipal landfills, the reduction of environmental impacts mainly on water as well as on land and mainly the birth of SMEs (micro, small and medium enterprises) that they are dedicated to waste revaluation. Of which we can mention, ferrous scrap, non-ferrous scrap, paper - cardboard, glass and plastic. Being innovative in the country the SMEs that are dedicated to the transformation of recycled waste into plastic wood for the use of the furniture and real estate sector of the country (Perez 2016).

In Ecuador, SMEs dedicated to the production of plastic wood from recycled waste are in the main cities Quito and Guayaquil. They have a production that varies between 30 to 40 ton / month, their main products are: profiles, floors / planks, benches, tables, playgrounds, pallets, among others (Albán 2019). Despite being a relatively new industry, it has a process under the principle of mold - compression, which requires recycled plastic waste to be: selected, crushed, extruded, molded and stored. Currently, the SMEs process has an empirical method for evaluating the quality of its products, which is based on types of plastics, times and temperatures. Therefore, it is necessary to investigate a formal method of statistical evaluation of operating parameters, which guarantees the quality of recycled plastic wood products in the market (Cruz 2016; Herrera et al. 2019; Herrera et al. 2019a; Herrera et al. 2019b).

Statistical quality control is an accurate tool to guarantee quality products, since it considers the variations that production processes generally have. These variations can be classified in the 6M: method, materials, labor,

machinery, environment and measurement. which, if not controlled, result in defective products (Krajewsky et al. 2008). Among the statistical methods and techniques most used for quality control are the control charts and graphs that can be applied in any production line (Pallavi et al. 2018). Aliverdi et al. (2013) present an approach to overcome the ability to report the accepted level of deviation by applying statistical quality control charts to monitor livestock value indices and Milo et al. (2015) show a new approach to automated manufacturing quality control. Other authors use statistical process control to evaluate the possibility of improving the process of obtaining a sanitary product (Hernández and Da Silva 2016).

In 2013, a statistical quality control was developed in chemical processes where control graphs were used, with the objective of reducing the variability of the processes and guaranteeing the maximum number of acceptable products and having a minimum waste (Besterfield 2009). The variables that were analyzed in this process were purity, viscosity and quantity manufactured. The postgraduate thesis in "Methodology to standardize processes in small Metal-Basic companies", considers as a methodology statistical control tools such as SPC (statistical process control) and acceptance sampling. In this implementation, as a result, products without defects and customer satisfaction were obtained (Mendoza 2011).

In Argentina the tools of statistical control constitute one of the basic tools to implement the so-called "Total Quality" philosophy. And it is demonstrated in his project: "Tools for monitoring and statistical control of attributes in high quality processes: study of results, computational implementation and practical application" (Joeques 2016). This is one of the many projects where statistical quality control tools are used to obtain acceptable products in the market, another similar case study was carried out in Colombia applying to the maintenance area where correct times for adequate maintenance were analyzed (Quintana 2013).

2. Materials and Methods

The research is carried out in three phases: in the first, the process of making recycled plastic wood will be diagnosed by characterizing the process. The second will determine the quantitative variables - qualitative market - process and define the appropriate control method for each. The third phase will implement the appropriate statistical quality control that will identify whether the process is stable or not. Where the results of the implementation will be evaluated.

a. Diagnosis of the production process of recycled plastic wood.

In the diagnosis, the process will be lifted through the construction of the SIPOC matrix. This activity will be carried out through the observation method in the plant, where data of inputs, subprocesses and outputs will be collected to determine the process.

Then a quality check list will be constructed with which it will be identified if the processes have quality assessment points. However, the following steps will be followed: first, the work group will investigate the requirements that a quality product must have. For which the following questions will be answered YES or NO: Is a procedure followed? Is the equipment calibrated? Is the machinery serviced? Are there standardized measures?. Are there control points for the quality? And is the final product compliant? By mutual agreement, the work team will determine the answer to each question. Second, a double entry table will be developed that shows the activities of the process versus questions that answer in the first step. Having this information registered, it will be tabulated and determine whether the implementation of statistical quality control in the production process is feasible.

Next, the client's voice (VOC) will be executed, to identify the needs and quality requirements of the final client. Bibliographic reviews will determine the specifications or properties of plastic wood versus common wood. With which a comparative table will be constructed between the client's specifications and the variables of production of recycled plastic wood for the production process.

b. Identification of the quantitative and qualitative variables of recycled plastic wood.

Qualitative and quantitative variables will be identified by the method of observation in plan. At this stage all the variables existing in the production process will be considered and recorded. They will then be classified by type of

variable (quantitative and qualitative) and will be related to customer specifications (specified in point a), within a relationship matrix.

The critical variables will be selected through the relationship table, using numerical weights, where the degree of relationship between them will be determined. The weights are given from zero (0) to five (5), five representing the highest degree of relationship and zero has no relation whatsoever. To select each of these variables, the area manager, team leaders and process operators will be surveyed. With which, the variables that directly affect the final characteristics of plastic wood will be determined. Next, with the working group, the method of qualitative variables control will be defined, this being the process cards as the most optimal method that shows step by step how to follow a procedure and thus be able to standardize it.

On the other hand, for the quantitative variables the control method is selected from the revision of the state of the art, having as reference 20 investigations as shown in table 1.

Table 1. Bibliographic review of control methods for quantitative variables.

Methodology	Research	Percentage
Statistical Control Charts	15	58%
Ishikawa diagram	3	12%
Statistical processes control	2	8%
Normality test	1	4%
Descriptive Analysis	1	4%
Control Diagrams	1	4%
Six Sigma	1	4%
Acceptance Sampling	1	4%
Histograms	1	4%

After carrying out the respective tabulation of the data we have that, of 20 quality control investigations 15 have been resolved through control graphs, representing 58% of the other methods. Therefore, control charts will be used to evaluate quantitative variables. The calculation of the sample will be carried out for the construction of the control charts of quantitative variables. The production lot has 4 sheets of recycled plastic wood per shift (Pozo, 2019), that is 5 lots per week. With which the sample is calculated using the following formula:

$$n = \frac{N\sigma^2z^2}{e^2(N-1) + \sigma^2z^2} \quad (1)$$

Where:

Z = The 95% confidence value indicates a constant value of 1.96

N = 20 represents the study population.

$\sigma = 0.5$ a constant value because the standard deviation of the population is unknown.

$e = 0.05$ corresponds to the sample error.

A confidence level of 95% and a sample error of 5% were considered.

Replacing values, we have:

$$n = \frac{20(0.5)^2(1.96)^2}{(0.05)^2(20-1) + (0.5)^2(1.96)^2}$$

$$n = 19,308$$

From this it is determined as a sample 20 sheets of recycled plastic wood in 5 batches of weekly production. This means that for this case study, the total production is equal to the defined sample. This is because the simulation laboratory produces small batches.

Then the amount of data indicated by the sample will be collected and the average, range and standard deviation will be calculated, as well as a normality test, which will facilitate the preparation of the control chart in the computer tool.

c. Implementation of statistical quality control.

For qualitative variables, a check list of the steps defined in the process files will be executed. While for the quantitative variables a sheet will be implemented, where the operational staff will build and analyze control charts.

3. Result and Discussion

a. Diagnosis of the production process of recycled plastic wood.

In Table 2, the SIPOC matrix of the recycled plastic wood production process is presented, where five subprocesses can be observed. These are: reception of raw material, selection, crushing, mixing and molding. It should be noted that currently the production activities of plastic wood are defined empirically, without evaluation methods for product quality.

Table 2. SIPOC matrix of the recycled plastic wood production process.

Supplier	Entrances	Process	Out	Customer
Storage	*Recycled polymer *Vegetable fiber	Select recycled polymers and vegetable fiber	*Polymer type *Vegetable fiber selected	Crushed
Selection	*Polymer type *Vegetable fiber selected	Triturate polymers and vegetable fiber	*Polymer falke *Powdered vegetable fiber	Formulation
Crushed	*Polymer falke *Powdered vegetable fiber	Mix polymer flake and powdered vegetable fiber	*Composite material	Modeling
Formulation	*Composite material	Foundry composite material	*Molten composite material	Compacted
Modeling	*Molten composite material	Compact molten composite material	Recycled plastic wood	End customer

Table 3 shows the Check List for quality control in the production of recycled plastic wood. Which presents 6 questions and answers that define if the current process complies with some method of statistical control of the quality of the finished product.

Table 3. Check List for quality control in the production of recycled plastic wood.

Subprocesses	Is a procedure followed?	Are the teams fund calibrated?	Is machinery maintenance performed	Are standardized measures established?	Are there quality control points?	Is the final product compliant?
Raw material classification	no	no	no	no	no	yes
Crushed polymers	no	no	no	no	no	no
Spraying of vegetable fibers	no	no	no	no	no	no
Mixture	no	no	no	yes	no	yes
Molded	no	no	no	no	no	yes

Pressing	no	no	no	no	no	no
Compliance (%)	0%	0%	0%	16.6%	0%	49,8%

After having carried out the check list of the statistical quality control in the production of plastic wood, it was determined that the process does not have procedures. The equipment is not calibrated and is not performed maintaining. In addition, there are no quality control points in any area of each thread. The percentage of compliance with standardized measures only represent 16.6%. And the compliant outputs of the process represent 49.8% compliance with the 6 threads. By knowing the shortcomings of the plastic wood process, the wood specification is determined by (VOC), as shown in table 4.

Table 4. Wood customer specifications.

Wood properties	Physical properties	*Resistance *Density *Thickness *Durability
	Technological properties	*Color *Size

After a bibliographical investigation, it was possible to determine that in both plastic and conventional wood, the client searches the market for the following properties of: resistance, density, thickness, size and how the color is finished. It should be considered that these are the properties that customers want to consider a quality product.

b. Identification of the quantitative and qualitative variables of recycled plastic wood.

To enter the analysis of variables, a matrix was made that shows the relationships that the process variables have with the properties of plastic wood. Table 5 shows the summary of the relationship between wood properties and the variables (quantitative-qualitative) of the process. Here, each variable to be evaluated is shown to meet the customer's specification.

Table 5. Matrix of relationships between specification and critical variables.

Specifications	Selection	Crushed	Sprayed	Mixture	Molded	Compact
Resistance	Polymer type			Mixing percentage	* <i>Molding time</i> * <i>Temperature</i>	* <i>Pressure</i> * <i>Pressing time</i>
Density	Polymer type Vegetable fiber			Mixing percentage		* <i>Pressed time</i> * <i>Pressure</i>
Espesor Thickness		<i>Flake size</i>	<i>Flake size</i>	Mixing percentage		<i>Pressed time</i> * <i>Pressure</i>
Color	Polymer type			Mixing percentage	<i>Molding time</i>	
Durability				Mixing percentage		

* **Bold:** Qualitative variables

* *Italic:* Quantitative variables

From table 5 it is determined that the main variables that affect the quality of the product in each subprocess are: qualitative such as the type of polymer, type of vegetable fiber and type of mold. As quantitative variables, the percentage of mixing, pressing time, pressure, flake size and molding time. Having the study variables ready, each one is measured in their respective areas or subprocesses. Table 6 shows an example of a control for the qualitative polymer type variable, in the format of the process sheet that includes the mission, inputs, steps, outputs and the name of the control variable. By complying with this sheet, compliance with standard activities is guaranteed.

Table 6. Process control sheet of the polymer type variable selection area.

Plastic Wood	Process Sheet: Classification of the type of polymer in the selection area	
	Code:	Pages:
Process Mission		
Perform the correct classification of polymers in the area of raw material selection to guarantee the strength of the final product.		
Procedure		
Entrances	Steps	out
Packaging of different materials	1.Remove the labels from each plastic container to be able to visualize the identification symbol. 2. Find in each container the triangle with numbering 2 that indicates the high-density polyethylene. 3. Place the selected containers in a container. 4.Label the selected container container with the name "PEHD high density polymer selected"	* High density polyethylene classified and labeled
Containers		
Tags		
Control Variable:	Type of polymer selection area	

In the same way, the control form for the quantitative variables as shown: defective flake quantity, pressure and temperature.

Control of the quantitative variable quantity of defective flake in the crushing area: as I had mentioned for the control of the quantitative variables, the control graphs are used, which are constructed from data collected by a sample size 5 lots, and with this the normality test is carried out as shown in Figure 1.

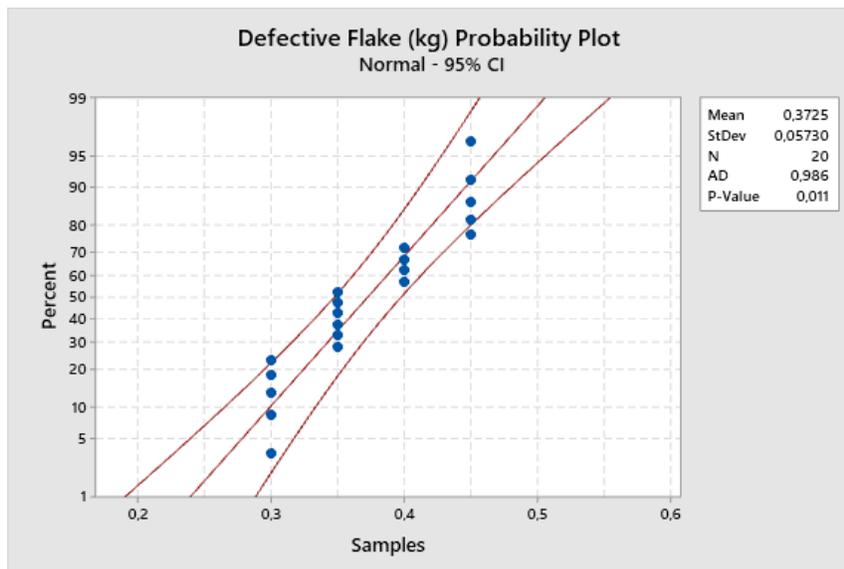


Figure 1. Normality test for the quantitative variable defective flake percentage.

If the data is non-normal, a greater number of false alarms can be observed, since less than 2% of the points are outside the control limits in graph I. The normality test is not necessary. (Minitab, 2016). According to our probability graph, we propose two hypothesis tests that will help to take actions, thus having:

H0: The data follow a normal distribution.

P> α value: The data follow a normal distribution.

H1: The data does not follow a normal distribution.

P value $\leq \alpha$: The data does not follow a normal distribution

$$H1: p \leq \alpha: 0,01 \leq 0.05$$

Therefore, H1 is accepted and H 0 is rejected.

We verify that the data is not normal but since they do not represent more than 2% of points outside the limits, we proceed to make our control chart by variables. Type I-MR (Individual data and mobile ranges) that monitors the average and variation of a process. Figure 2 shows the behavior of the defective flake quantity variable for each kg of flake analyzed.

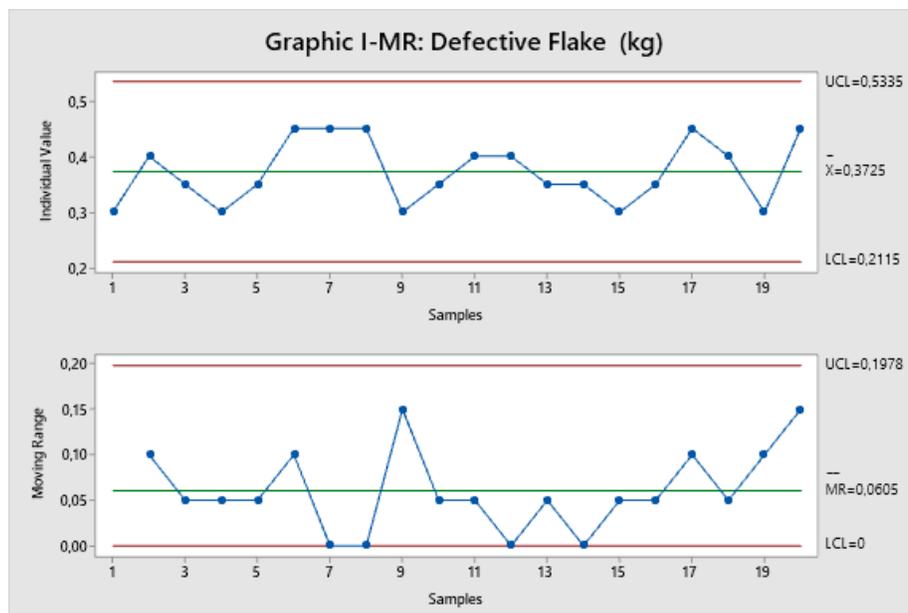


Figure 2. Control chart - Variable quantity (kg) of defective flake.

From figure 2 it can be determined that the process is stable and there is no point out of control. We conclude: that there is stability since the average - variation of the process are stable and have no points out of control in any graph. In addition, we can standardize the amount of defective flake that may exist for each kilogram evaluated, this being 0.53 kg as the maximum value. If this value is exceeded, the process must be stopped, and the source of the fault must be sought, and corrective actions taken.

Control of the quantitative temperature variable in the molding area: the sample size will be the same for all quantitative variables. Therefore, 20 measurements were taken since the mold enters the oven and the temperature reaches 110 ° C. With the data we proceed to make the control graph in the software, as shown in Figure 3. It is convenient to indicate that the same program calculates the average and the control limits, so that no calculation will be necessary.

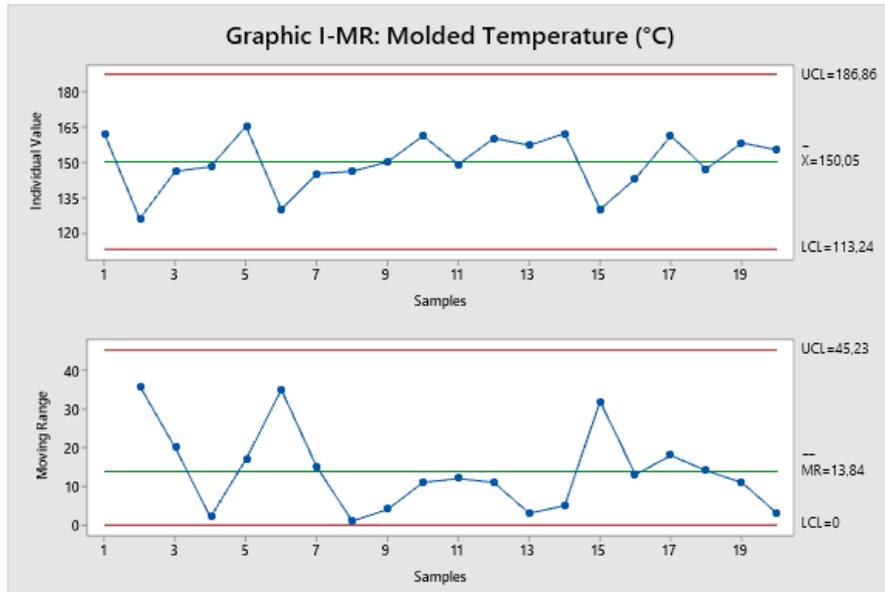


Figure 3. Control graph for the temperature variable in the molded area.

Figure 3 shows no instability in terms of the temperature variable in the molding area. We can conclude that the set of data taken at the temperature variable is normal since no point is exceeding the control limits. In addition, the molding activity is stable as the average indicates. Therefore, the standard values in this area are given by an upper limit of 186.86 °C, in other words, if it exceeds this limit, there will be failures in the resistance specification of the final product, in the same way if the temperature is very low. For this reason, it is recommended to work with the value of the nominal average temperature that is 150°C.

Control of the quantitative pressure variable in the pressing area: In the same way, the sample size data is collected and the software for the construction of the control graph of the pressure variable is entered, as shown in Figure 4.

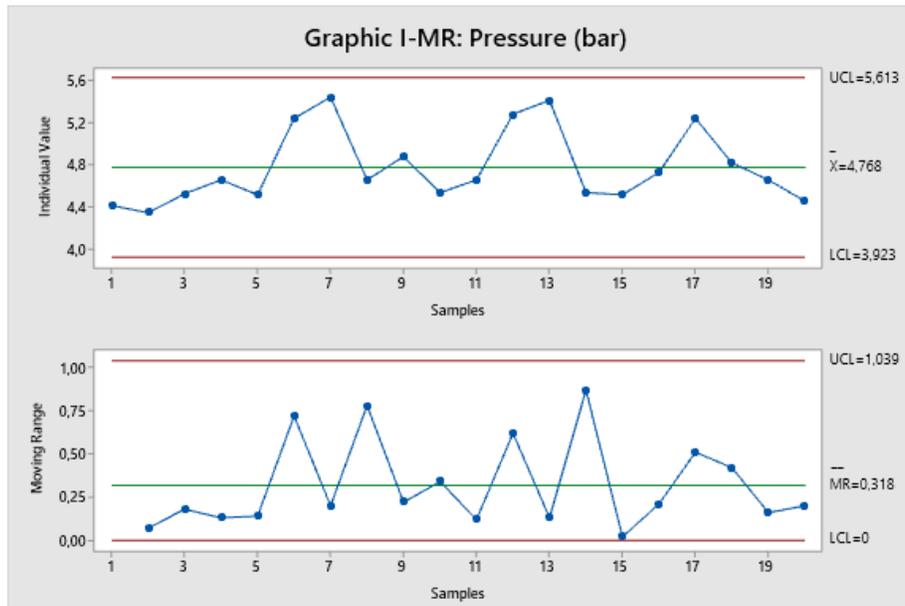


Figure 4. Control chart for the pressure variable in the compact area.

The points analyzed were the normality of the data, the stability of the process and the control limits, for which we have that a normality test is not necessary since no value that represents 2% of the total data is outside the limits, this guarantees that the process is stable with respect to the average. In addition, we can define a standard value of 4.76 bars to obtain a correct press that guarantees hardness and density of plastic wood. Table 6 shows a summary of the standard values obtained from the construction of these graphs.

Table 6. Summary of standard values for quantitative variables

Var	Standard Value
Defective flake	0.37 Kg
Temperature	150° C
Pressure	4.76 bar
Molding time	36 min
Pressing time	26 min

c. Implementation of statistical quality control

For qualitative variables there is a process sheet in each area which must be read and applied step by step to ensure adequate control compliance with the qualitative variable. For each step completed, the person in charge of the process must mark with a nod (√) that this step has been completed and therefore the variable has been controlled. Table 7 shows an example of the check list for the control of the qualitative variable type of vegetable fiber.

Table 7. Check List for control of the qualitative variable type of vegetable fiber.

Items	Yes	No
1. Visually identify that the fibers introduced to the laboratory are mixed or contain impurities		
2. If the fibers are in a container and comply with the previous step proceed to label with the name of the fiber Example: "Selected Rose Vegetable Fibers"		
3.If the fibers do not have any container, go to the reception area of raw material and look for one that is empty and does not contain any labels.		
4. Label the container with vegetable fibers with the name of the fiber Example: "Selected Rose Vegetable Fibers"		
Observations:		
Responsible	Date	Firm

On the other hand, table 8 shows the format for controlling quantitative variables such as the amount of defective flake measured in kg in the crushing area, temperature and pressure. For the time variables of the molding and pressing threads, the person responsible for the process must control the standardized time, represented in table 6.

Table 8. Control sheet of the quantitative variable.

Types of Quantitative Variables			
Flake size		Pressure	Temperature
Objective:	Control quantitative variables using a control chart in plan		
Construction steps	1. Take samples of the variable to be controlled		
	2. Record the data in the attached table		
	3. Locate the data collected on the graph (X, Y)		
	4. Join with a continuous line all the data in the control chart.		
	5. Observe if the points remain within the range of the upper and lower limits, if this happens continue, otherwise stop the process and look for the causes of the error.		
No. Samples	Unit of measurement ()	Control chart of the quantitative variable	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Observations:			
Responsible		Date	Firm

The implementation of the statistical control of the quality of the production process of recycled plastic wood resulted in a controlled process, which correctly guarantees the performance of each subprocess of the production area, thus ensuring the quality of the final product. The evaluation of the results of the recycled plastic wood was carried out through the analysis of the tensile strength, in table 9 the comparison of the properties before and after the implementation is indicated.

Table 9. Comparison of the properties of plastic wood before and after

Properties of plastic wood	Before	After
Force Max. (N)	605,42	751,03
Elongation at max. force (%)	3,05	3,68
Breaking force (N)	445,06	316,51
Elongation at break (%)	3,39	3,87
Density (g / cm ³)	1,76	1,71
Coefficient of variation (%)	51,38	7,26

Looking at the values in table 9 we can show an improvement in the properties of plastic wood, such as the maximum force applied that has increased by 24% of the initial value, where no quality control was performed. As for the elongation force, that is, when the material begins its deformation, the percentage of improvement is 17.11%. The breaking force decreased by 28.88% since the greater the maximum force, the lower the elongation of the material.

By maintaining the same formulation for the specimens before and after implementing statistical quality control, the density did not vary greatly, thus decreasing only 0.05 kg, that is, the material remains light. In addition, we can observe that the coefficient of variation has totally decreased from 51.38% to 7.26%, due to the fact that there are now control points in each area of the process that allow the qualitative and quantitative variables in the production of production to be kept under control. plastic wood.

4. Conclusions

The initial diagnosis was determined, each of the subprocesses that make up the plastic wood production process were defined, as well as to identify the quantitative and qualitative variables present in each area and in this way designate the strategic places that needed a control point that guarantee the quality of the product, which were: the raw material reception area, crushing, molding and pressing area, which now have a quality control tool.

It was identified that the production of recycled plastic wood is a process whose production volume is low, for this reason, for the control of quantitative variables, the individual graphs of mobile ranges (I-MR) were implemented that allowed to detect the variability and stability of the process. On the other hand, since the qualitative variables are difficult to quantify, a control tool (process sheets) was designed that allows activities to be carried out in an orderly manner and thereby guarantee a standardized procedure.

As for the strength of the material, plastic wood is produced with a maximum resistance value of 751.03 N and with 316.51 N of breaking strength. It was also possible to standardize the time variable in the molding and pressing area, being these 36 and 26 minutes respectively, the temperature in the molding area could be standardized with a value of 150 ° C and in the pressing area the correct pressure for guarantee the hardness of plastic wood sheets is 4.76 bars.

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