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Minimization of Drying Time in a Resin Process Using Design of Experiments

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Abstract: Statistical control tools are a set of knowledge, techniques, and methodologies that support us to give complete visibility to the panorama of production processes. The importance of the application of these tools is based on the analysis of the current factors, the analysis of the ideal factors, and knowing the distance between these two variables gives us an idea of what we can do to achieve a specific objective. The present research seeks to implement a design of experiments, containing a mathematical model, in a SME dedicated to the creation of molds with resins and mass copies of certain objects, in this particular case, the process involves the use of different chemicals and catalysts to make the copies. The objective is to know which the interaction between the chemicals is and to achieve a way to minimize the drying time and thus have a shorter process, and to be able to develop standardization in the use of the same components in the process.

Keywords: Statistical control, Optimization, SME

1. Introduction

Today many companies are in constant need to improve their performance and have the perfect formula for the best design in their operation. And sometimes, when companies have not been enough time with an established operation process, it can become an impossible task. For small and medium-sized enterprises, good control over operations can become a vital factor in distinguishing themselves from the competition. The implementation of statistical models in the companies' production processes; could be a requirement in mass production companies. However, for small companies, it is not a very common task. And such statistical models can help them to determine what are the optimal conditions to work with any type of labor input, from monetary to components that interact as inputs within the process.

1.1 Context

The following research takes place in a company founded in 2013, in the city of Monterrey, Nuevo Leon, Mexico. Where work and projects are carried out, in the area of graphic and industrial design, with applications of screen printing processes, elaboration of plastic modeling, and where most of the production process is focused on the creation of objects, replicas, and models through a process of molding through a set of resins, catalysts, and silicones.

1.2 The objective of the study and definition of the problem

Within the production process of molding, drying time (a vital factor in customer service and variable response to the combination of various components), can take a large number of hours, even sometimes you have to wait until the next day to see the production finished. Through the implementation of a statistical model, we would seek to know how much the process varies in the face of the interaction of all its inputs and look for the way that with the least amount of materials we can have the shortest drying time, having significant benefits in profits (lower purchase of resources and more satisfied customers). (Kazmier, L. J., 1998)

2. Explanation of the current process

To create a replica or an object through molding. It is necessary to have a study object to be replicated (three-dimensional physical figure), a set of clay or sand that allows us to create support (to pour silicone on it that will take the shape of a face or half of the object). The intention is to print the faces or halves of the three-dimensional object in a silicone mold, and when removing the original object, fill the spaces with a resin that solidifies. The components that enter directly into the production process, is the rubber silicone with its respective catalyst (which helps it solidify more quickly) and the resin (a liquid that at the end of time, solidifies and becomes the new replicated object).

Substance required	**Concentration and/or variation**	**Current price**
Mold Max-30 (rubber silicone)	It is achieved per kilogram.	$ 398.46 MXN
Polylite Resin 33004-00	It is achieved per kilogram, has no variations.	$ 68.55 MXN
Norox MEKP-925 Catalyst	It is achieved by dropper (10%, 20%, 30%, and 40%).	$ 16.24 MXN
Rubber silicone catalyst 25%	It is achieved per liter, must be obtained per order, has concentrations of 15%, 20%, 25% maximum, intermediate measures can be obtained.	$ 18.25 MXN

Figure 1. Substances and concentrations

The last part of the process is to remove the rubber silicone with caution and remove the solidified resin (the same silicone mold can be used a lot of occasions if the silicone is removed carefully, the resin does not adhere to the rubber silicone and is removed very easily).

Figure 2. Experimental process of elaboration, in the first photograph you can see the placement of the study object in the mold, in the second the emptying of the rubber silicone, in the third the creation of the resin, and finally the emptying of the resin in the rubber silicone mold.

3. Methodology

For this particular research, it will be sought to implement a methodology of the field of statistics, known as the design of experiments or factorial design, where some runs or experiments will be performed in the face of the interactions of the components that are used in the process (Montgomery, D. C., 2015), the response variable (drying time) will be evaluated for all combinations, and searched through the model, get the optimal combination that makes us have the shortest drying time. With this context, the research will be sought through the following phases:

1. Knowledge of the components that interact with the process and its levels
2. Choosing the object to replicate
3. Variable hypothesis and variable interaction
4. Conducting experimentation runs and process documentation
5. Data management

3.1 Knowledge of the components that interact in the process and their levels

Within the process, we have two main components coexisting, catalysts with their respective inputs, the catalyst with rubber silicone, and catalyst with resin, and as an additional factor, it is inferred that within a drying process, the ambient temperature could be affecting the result of the experiment in the same way. In an experiment design it is necessary to list all the elements that would be affecting the response variable, which in this case, is the drying time, and its minimum or maximum concentration for each, in this case the maximum concentrations recommended by the distributors of the materials were taken

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as reference, in the case of temperature the maximum and minimum temperature adjustable in a small production workshop is taken as reference.

Variable	**Low level (-)**	**High Level (+)**
Concentration of rubber silicone catalyst	10%	40%
Resin catalyst concentration	15%	25%
Temperature	15 °C	30°C

Figure 3. Input variables with their low and high levels

3.2 Choosing the object to replicate

The process can be complex when it is a three-dimensional object with different variations in measurements and would involve the use of a double mold to be able to replicate both parts, so it was decided to replicate a commemorative coin of the Apollo 18 (5 centimeters in diameter), in order to make the study less expensive and have a little more agility in doing so. The study only involves replicating one of the sides of the coin.

3.3 Variable interaction hypothesis

The hypotheses within the project involve whether each variable separately is relevant to differ as a significant impact on the response variable (through its variation), and whether the interactions between the A-B, A-C, B-C variables are significant or have a result within the response variable. (Montgomery, D. C., 2015)

- Does handling from a low level to a high level of the catalyst in rubber silicone have an impact? (τ)
- Does handling from a low level to a high level of the catalyst in the resin have an impact? (β)
- Does manipulating from a low level to a high level in temperature have an impact? (γ)
- Interactions between all of them.

For the ratio of low and high levels of the rubber silicone catalyst

$$Ho\colon \tau_1 = \tau_2 = 0$$
$$H1\colon \tau_i \neq 0 \; for\ at\ least\ i = 1, 2 \tag{1}$$

For the relationship between low and high levels of the resin catalyst

$$Ho\colon \beta_1 = \beta_2 = 0$$
$$H1\colon \beta_j \neq 0 \; for\ at\ least\ i = 1, 2 \tag{2}$$

For the ratio of low and high temperature levels

$$Ho\colon \gamma_1 = \gamma_2 = 0$$
$$H1\colon \gamma_k \neq 0 \; for\ at\ least\ i = 1, 2 \tag{3}$$

Subsequently for combinations between 2 treatments.

$$Ho\colon (\tau\beta)_{11} = (\tau\beta)_{12} = \cdots = (\tau\beta)_{22}$$
$$H1\colon (\tau\beta)_{ij} \neq 0$$
$$Ho\colon (\beta\gamma)_{11} = (\beta\gamma)_{12} = \cdots = (\beta\gamma)_{22}$$
$$H1\colon (\beta\gamma)_{jk\neq 0}$$
$$Ho\colon (\tau\gamma)_{11} = (\tau\gamma)_{12} = \cdots = (\tau\gamma)_{22}$$
$$H1\colon (\tau\gamma)_{ik} \neq 0 \tag{4}$$

Subsequently for combinations between 3 treatments.

$$Ho\colon (\tau\beta\gamma)_{111} = (\tau\beta\gamma)_{112} = \cdots = (\tau\beta\gamma)_{222}$$
$$H1\colon (\tau\beta\gamma)_{ijk} \neq 0 \tag{5}$$

For curvature;

$$Ho\colon \beta_{11} + \beta_{22} = 0$$

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$H1\colon\ \beta_{jj}\ \neq 0$ (6)

3.4 Conducting experimentation runs and process documentation

The direct application of the project consists of a factorial design of 2o3, with 10 runs or replicas for each combination (8 different combinations), this with the purpose of generating the most robust analysis possible. Below is the table with its different levels, you can see the titles of the 3 variables or factors that are proposed that could affect the model, also included within the same table the 10 runs mentioned above under the conditions of each proposed block.

Rubber silicone catalyst concentration	Resin catalyst concentration			
	15 %		25 %	
	Temperature		Temperature	
	15 °C	30 °C	15 °C	30 °C
10 %	29.22	28.93	25.68	24.92
	29.07	28.84	26.03	24.63
	28.66	28.97	25.33	24.15
	29.05	28.67	25.45	23.67
	29.08	28.73	25.47	24.11
	29.22	28.69	25.14	24.56
	29.51	28.56	26.13	23.98
	28.93	28.74	25.22	24.48
	29.13	28.52	25.25	24.13
	28.97	28.96	26.11	24.56
40 %	12.45	11.23	9.45	8.03
	12.41	11.03	9.88	7.98
	12.39	10.64	9.56	7.89
	12.28	10.97	9.54	8.24
	11.99	11.69	9.22	7.96
	12.06	11.32	9.65	8.12
	12.28	11.58	9.63	8.23
	12.24	11.72	9.75	8.24
	12.33	11.45	9.39	8.22
	12.41	11.71	9.71	8.05

Figure 4. Matrix of information collected for combination of factors.

3.5 Data management

The following information is compiled for the automatic computed execution of the hypothesis check through the indicated levels, combinations and all observations collected in each block. The model involves the analysis of 80 particular data (grouped into 8 blocks of 10 runs each) and the intention is to know which variables alone are relevant, and which interactions are relevant.

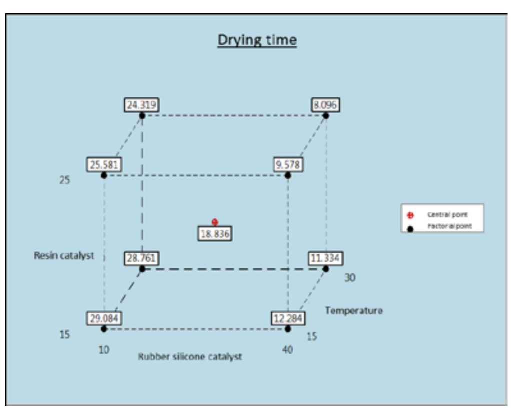

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Figure 5. Cube graph for factorial design combinations

The cube graph shows the possible combinations of levels and their respective average drying time, this table helps to understand a little bit on how the model behaves based on the captured observations, responses or data that appear within the edges, which would become predicted values about each combination.

4. Results analysis

Variation source	Degrees of freedom	F-Value	P-Value
Model	8	10425.86	0.000
Linear	3	27759.02	0.000
Rubber silicone catalyst	1	79513.15	0.000
Resin catalyst	1	3473.38	0.000
Temperature	1	290.55	0.000
2-term interactions	3	41.32	0.000
Rubber silicone catalyst*Resin catalyst	1	72.09	0.000
Rubber silicone catalyst*Temperature	1	12.92	0.001
Resin Catalyst*Temperature	1	38.96	0.000
3-term interactions	1	2.98	0.088
Rubber Silicone Catalyst*Resin Catalyst*Temperature	1	2.98	0.088
Curvature	1	2.98	0.093
Error	76	-	-
Total	84	-	-

Figure 6. Value Analysis F vs. P-value

By analyzing the model and using a 95% degree of certainty, we can say that there is sufficient evidence to assert that the concentration of the rubber silicone catalyst (A), the resin catalyst concentration (B), and the temperature (C) significantly affect the drying time of our production process (variables alone).

In addition, there is some interaction between rubber silicone catalyst and resin catalyst, between rubber silicone catalyst and temperature, and also between the resin catalyst with temperature. On the other hand, no interaction is observed between the three variables, there are only significant effects when interacting in pairs.

On the other hand, thanks to the use of center points, we can also say that with 95% certainty, that there is no curvature type in the model, so it is reliable, viable or credible to use a linear regression model. Finally, you can see that a coefficient of determination R-2 was obtained, in which you can see the variability of the process based on the variables that were rejected (which if they have a significant differentiating effect), which in this case all the main factors, subsequently also the interactions of 2 factors, and the variability is 99.91%.

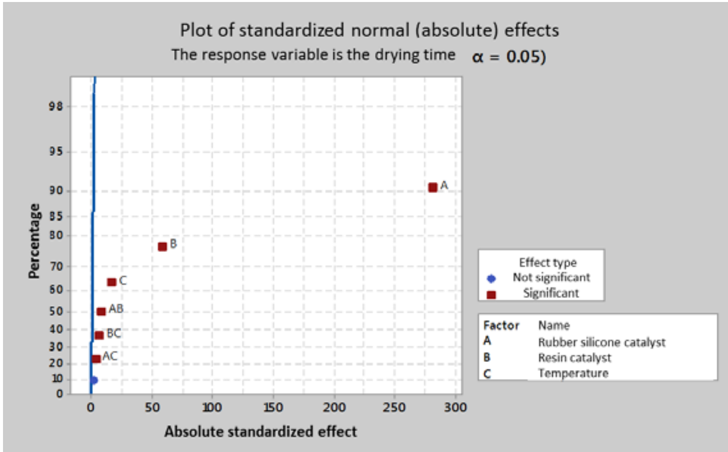

Figure 7. Graphical representation of significant variables and interactions.

The regression equation, or linear statistical model which can be trusted because there is no curvature as presented below. It was obtained thanks to the effects mentioned above, only those that were rejected or are significant and the great average.

$$\text{Drying time} = 38.839 - 0.5586\, x_1 - 0.2694\, x_2 + 0.0999\, x_3 + 0.00130\, x_1 x_2 - 0.00275\, x_1 x_3 - 0.00716\, x_2 x_3 + 0.000090\, x_1 x_2 x_3 \quad (7)$$

When concluding that the hypotheses are real, a minimization adjustment is made, indicating under what conditions the minimum response variable is obtained. Low which blocks in particular, we have the high lowest average.

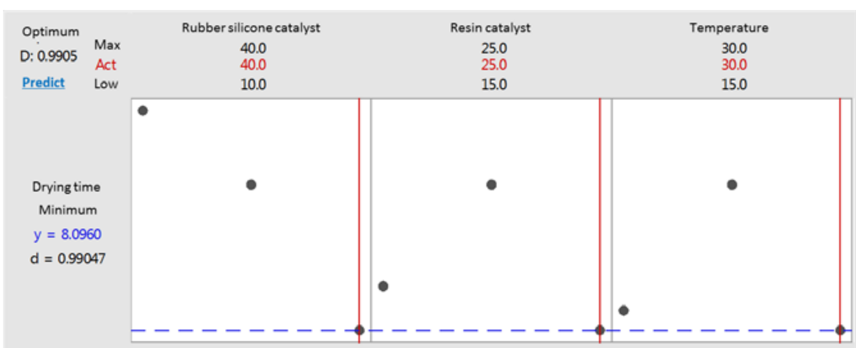

Figure 8. Minimization result

The graph shows that if it is necessary to minimize the drying time we have to choose the point with the highest levels, concentration of the catalyst in rubber silicone at 40%, concentration of the resin at 25%, temperature at 30oC, and this would allow to minimize the minimum response variable under the current possible conditions and the maximum allowed by suppliers of this type of products.

5. Conclusions

For this company, it is better to use the maximum concentrations already mentioned, to be able to go from runs that on average took 29 hours or possible runs with an average of 8 hours. The study also supports giving visibility of the temperature factor, and while choosing to perform the current process in an environment with artificial temperatures (small workshop), it is a little more convenient to use the ambient temperature to achieve better results in the drying time. A factor that is important to be included in the study.

Statistical analysis should be a requirement for both mass production companies and small businesses, because with a not very expensive investment of time and resources (experimentation), we can know how our process actually works, and what the ideal conditions for this process to work are. Finally, knowing all these factors we can have a great positive impact on the response of our customers and on how we use our resources (using higher concentrations does not necessarily imply greater expense, since it represents small amounts through drippers and the misused of these concentrations can trigger lost production). Standardizing this particular process is the next step for our study company, and having good monitoring of post-experimentation results.

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