Methodology for Formulation of Masses for Ceramic Coating Using the Loss Function

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Abstract: The present work aims to propose an experimental methodology based on experimental modelling for the formulation of ceramic masses to be used as ceramics coating. The project of simplex mixtures in pseudo-components allowed reducing total number of experiments to the optimal minimum number. Six raw materials were considered as control factors: talc, quartz, limestone, dolomite, phyllite and clays. The analyzed output responses was the linear retraction, bending resistance and absorption of water which were selected in account customer needs since they strongly affect the quality of the ceramics products during the production process.

Introduction

This article presents the optimization of masses ceramic for coating based on mathematical expression denominated as loss function, which allow selecting the best mass among a treatment group elaborated at a planning matrix. This criterion take in account the characteristics types of the required qualities, respecting the interests of the types “major is better” and “minor is better.”

The experiments design for Simplex mixtures is one of the available options for a systematic study of formulation of ceramics masses and lead a good understanding of the interactions that can exist between the components of the mixture.

Experimental design

The planning matrix was elaborated using as reference a ceramic mass pattern produced in a local industry, that is designed MP.

The transformation for pseudo-components was obtained by using equation bellow [1,2,3]. The obtained values are showed in Table 1, in the column “codified levels.”

\[ X'_i = \frac{X_i - L_i}{1 - \sum_{i=1}^{6} L_i} \]  

Eq. 1

Equation: \( X'_i \) represents the value in pseudo-components \( i \), \( \sum L_i \) is the addition of the inferior limits of the components, and \( X_i \) is the real percentage of the component \( i \).

Table 1 shows the planning matrix with the 21 elaborated masses and the MP mass, in terms of real formulations and in pseudo-components.
Table 2 shows the individual modelling of the responses for the quadratic model. It can be observed, that quartz addition when combined with limestone provokes a reduction in the linear retraction combined with a maximum bending resistance. These conflicting results, force to find conciliatory solution in order to optimize the ceramic masses. This subject will be studied as follows.

### Discussion of results

Table 2 shows the individual modelling of the responses for the quadratic model. It can be observed, that quartz addition when combined with limestone provokes a reduction in the linear retraction given by the term -1.92 X2X3 and also a reduction in the bending resistance as show the term -169X2X3. However, in the production line the target is obtains a minimum linear retraction combined with a maximum bending resistance. These conflicting results, force to find conciliatory solution in order to optimize the ceramic masses. This subject will be studied as follows.

<table>
<thead>
<tr>
<th>Variable of Response (Yi)</th>
<th>R²</th>
<th>model quadratic</th>
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</thead>
<tbody>
<tr>
<td>Linear Retraction. (Y1)</td>
<td>97%</td>
<td>Y1 = 3.26X1+ 2.42X2+ 1.1X3+ 3.23X4 +1.48X5+ 3.07X6 – 1.79 X1X3 – 1.03 X1X5 – 1.92 X2X3-1.88 X2X4 – 1.42 X2X4 – 2.32 X3X4+ 2.01 X3X5 – 1.87 X3X6 – 2.48 X4X5+ 1.16 X4X6.</td>
</tr>
<tr>
<td>Bending Resistance. (Y2)</td>
<td>76%</td>
<td>Y2=147X1+136X2+135X3+167X4+116X5+165X6+142X1X4+101X1X5+116X1X6-169X2X3+114X3X5+96X4X5+96X4X6+119X5X6.</td>
</tr>
<tr>
<td>Absorption of water (Y3)</td>
<td>94%</td>
<td>Y3=13.12X1+17.35X2+20.65X3+15.85X4+22.27X5+15.5X6 – 5.15X1X2–4.0X1X5+6.6X2X3-3.9X2X4-13.65X2X5–2X2X6–10.75X4X5–5.20X4X6.</td>
</tr>
</tbody>
</table>
Optimization of the ceramic mass

The experimental methodology was accomplished according function quality loss. [4,5]. The loss function developed by Taguchi [6] was adapted to deduce an expression that represents the amount of the total losses for each mass.

The illustrations 1 and 2 interpret the behavior of the masses in function of the wanted response. Those responses are those that had larger approach of the target values, respecting the conditions: the target value is the inferior limit for responses of the type “as minor is better”; and the target value is the superior limit for response of the type “as major is better.” It tries to find an expression that represents the sum of the losses of found response. The figure 1 compares two situations when it is sought responses of the type “minor is better.”

Where:  
IL = Inferior Limits = target: it is the value that would be ideal, (minor is better)  
SL = it Limits Superior, it is the worst found response, (when minor is better)  
YMR is the response found for the reference mass, used in the industry.

It is noticed that Y1 > Y2, whose situation is more favorable for Y2 (minor is better), and (Y1 – IL) > (Y2 – IL), what implicates in a larger loss for Y1 (worse response).

For the cases of the type “major is better”, the figure 2 interprets the behavior of two responses, showing that the smallest losses happen when the largest response is had.

Figure 1 - Behavior of the graph for response of the type “minor is better”

Figure 2 - Behavior of the graph for response of the major type is better
The Equations (2) and (3) represents the calculation evolution of the quality losses for ceramic mixtures.

\[ \hat{Z}(I) = \frac{1}{\sum (LS-LI)^2 \times (IR) x [(Y_j-LI)^2]} \]  
Eq 2

\[ \hat{Z}(I) = \frac{1}{\sum (LS-LI)^2 \times (IR) x [(LS-Y_j)^2]} \]  
Eq. 3

For equation (2), minor is better:
L.I= Limit Inferior = Target: it is the value that would be ideal;
LS=Limit superior, is the worst found response, (when minor is better).

For equation (3), major is better:
L.I= Limits Inferior: is the worst found response (when major is better).
LS= Limit superior = Target, is the better-found response.
I.R: it is the relative importance (weigh) of the responses to each other. Those values can undergo alterations in agreement with the required priorities.
Y_i is the response found for the mass M_i.

Table 3 shows the results of the quality loss of the masses Z(i), using the Equations 2 and 3. The larger losses, in crescent order were: M19<M13<M10... \( \Rightarrow \) M19 was the best mass.

The optimization of loss model can be found in function of the independent variables X_i, because, Y=F(x) and Z=F(y) \( \Rightarrow \) Z = F(x). The expression represents the loss model Z(i) in the raw materials function: it is observed in absolute terms, that the dolomite is the raw material in function that more contributes with the loss of quality of the masses (10.16 X5), and clays tends to minimize the quality losses (2.82X6). In relative terms, phyllite and dolomite minimize the quality loss (–22.26X4X5):

\[ Z(i) = 2.92X1 + 3.66X2 + 7.53X3 + 3.41X4 + 10.16X5 + 2.82X6 + 1.08X1X2 – 3.9X1X3 – 3.54X1X4 – 17.44X1X5 – 2.72 X1X6 + 18.02X2X3 – 6.82X2X4 – 15.56X2X5 – 2.48X2X6 – 6.16X3X4 – 8.58X3X5 – 9.54X3X6 – 22.26X4X5 – 0.66X4X6. \]  
Eq. 4

The figure 3 shows the behavior of the masses with relationship to the quality losses.

![Figure 3: Behavior of the losses of quality.](image-url)
Table 3: Summary of the Losses of Quality of the masses.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>M1</td>
<td>2.24</td>
<td>0.00</td>
<td>0.68</td>
<td>2.92</td>
</tr>
<tr>
<td>M2</td>
<td>0.82</td>
<td>0.89</td>
<td>1.10</td>
<td>2.81</td>
</tr>
<tr>
<td>M3</td>
<td>0.00</td>
<td>2.83</td>
<td>2.29</td>
<td>5.12</td>
</tr>
<tr>
<td>M4</td>
<td>2.19</td>
<td>0.37</td>
<td>0.47</td>
<td>3.03</td>
</tr>
<tr>
<td>M5</td>
<td>0.08</td>
<td>4.19</td>
<td>3.08</td>
<td>7.35</td>
</tr>
<tr>
<td>M6</td>
<td>1.98</td>
<td>0.28</td>
<td>0.45</td>
<td>2.63</td>
</tr>
<tr>
<td>M7</td>
<td>1.59</td>
<td>0.03</td>
<td>1.90</td>
<td>3.53</td>
</tr>
<tr>
<td>M8</td>
<td>0.25</td>
<td>0.77</td>
<td>0.83</td>
<td>1.85</td>
</tr>
<tr>
<td>M9</td>
<td>2.19</td>
<td>0.04</td>
<td>0.01</td>
<td>2.24</td>
</tr>
<tr>
<td>M10</td>
<td>0.56</td>
<td>0.64</td>
<td>0.43</td>
<td>1.63</td>
</tr>
<tr>
<td>M11</td>
<td>2.09</td>
<td>0.01</td>
<td>0.09</td>
<td>2.19</td>
</tr>
</tbody>
</table>

LR.  Linear Retraction  BR:  Bending  Resistance  AW: Absorption of Water

Table 4 shows comparative data between the best mass selected among those elaborate at the planning matrix using the function loss (mass 19) and the mass pattern (MP).

<table>
<thead>
<tr>
<th>Mass A : Formulação (%wt)</th>
<th>B: codified Levels</th>
<th>R.L</th>
<th>B.R</th>
<th>W.A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass ↓</td>
<td>X1  X2 X3 X4 X5 X6</td>
<td>X1  X2 X3 X4 X5 X6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP</td>
<td>10  4  3 14 5 64</td>
<td>0.2 0.1 0.0 0.2 0.1 0.4</td>
<td>2.7 172</td>
<td>14.7</td>
</tr>
<tr>
<td>M19</td>
<td>8   3  3 17 9 60</td>
<td>0   0   0   0.5 0.5 0</td>
<td>1.8 166</td>
<td>16.4</td>
</tr>
</tbody>
</table>

LR:  Linear Retraction;  BR.  Bending  Resistance  W.  Absorption of Water

Conclusion

The equations of quality losses that were developed in this work, allowed selecting the best mass among the several ones of the planning matrix. The use of this technique for analysis of the experiments was shown to be effective to optimize the formulation of ceramic masses. It also showed a better understanding of the influences of the raw materials in the behavior of the response of the masses used in the industry. This can lead to the improvement of the quality of the final product, with less refuse and, consequently, with smaller production costs.
References


