# A METHOD TO OPTIMIZE CERAMIC MASSES FOR COATINGS USING THE LOSS FUNCTION

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***Abstract**. The present work has the objetive of proposing a* methodology for formulation of applied masses in ceramic coatings by the delineation of mixtures techniques, particularly, through mathematical expressions denominated Loss Function of Quality. The simplex mixture method in pseudocomponents allows to reduce to the minimum the number of experiments. Six raw materials were considered as control factors: talc, quartz, limestone, phyllite, dolomite and clay. The analyzed responses were those that affect the quality of the ceramic product: linear retraction, bending resistance and absorption of water. The characteristics of quality of the optimized ceramic body was comparated with the ceramic body elaborated in local industry.

***Keywords**: Project of experiments, Ceramic coatings. Delineation of ceramic mixtures.*

## 1. Introduction

In the production of ceramic coatings, mixtures of raw materials of several places with different physical and chemistries characteristics are used. Those changes of raw materials alter the qualities of the finished product, what implicates in the constant reformulation in the composition of the ceramic mass through attempt and mistake, consuming time and raw materials. The project of experiments for Simplex mixture is one of the available options for a systematic study of formulation of ceramics masses (Caten et all, 1998; Cornell, 1981), leading to a good understanding of the interactions among the components of the mixture.

Mathematical expressions called ***loss functions*** are developed to allow selecting the best mass among several of planning matrix. That criterion takes in consideration the types of characteristics of wanted qualities, respecting the properties of the types "major is better" and "minor is better", for instance: bending resistance and absorption of water.

## 2.Experimental Design

The planning matrix was elaborated taking as reference a ceramic mass produced in a local industry, with composition of 10% of talc, 4% of quartz, 3% of limestone, 14% of phyllite, 5% of dolomite and 64% of clay (here denominated reference mass RM) as having as output responses: 2,3% of linear retraction, 172 kgf/cm$^2$ bending resistance and 14.7% of absorption of water. Those response were improved through a method to optimize ceramics masses that was developed in the following stages: (1) Identification of the problem, where the objectives of the study and the characteristics of quality of the product were defined; (2) Planning and execution of experiments, where the experiments were analyzed according to the DOE-Design Of Experiments (Montgomey, 1991), having as controllable factors the percentage of the raw materials; (3) Optimization and discussion of the results. The modeling was developed through linear regression of the response in function of the control factors. The optimization of the ceramic mass was accomplished through the criterion of loss function.

The transformation for pseudocomponents (Benício et all, 2000), resultant of the application of the equation 1, gives the values of Table 1, in the column "codified levels."

$$X_i' = \frac{X_i - L_i}{1 - \sum_{1}^{6} L_i} \qquad (1)$$

Where: X'i represents the value in pseudocomponents i, Li is the low limits of the components, and Xi is the true percentile of the component i.

Table 1 shows the planning matrix with the 21 elaborated masses Mx and the reference mass RM, in terms of real formulations and in pseudocomponents. The compositions were processed in the following conditions: grinding for 2 hours in mill of balls type rotative cylindrical drum of porcelain, using porcelain spheres. The masses were sifted in mesh 200, drought in furnace to 110ºC and compacted in matrix uniaxial with puncture of 50mmX150mm. An automatic hydraulic press was used with capacity of 100 tons and applied a pressure of 216 kgf/cm$^2$. The ceramic product was burned in rolls of industrial furnace, to temperatures of 1180 ºC. These processes were the same ones adopted by the industry.

Table 1 - Matrix of planning of the elaborated masses

| The: Formulation of masses (%wt) | | | | | | | B: codified Levels | | | | | | The: Formulation of masses (%wt) | | | | | | | B: codified Levels | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | X2 | X3 | X4 | X5 | X6 | X1 | X2 | X3 | X4 | X5 | X6 | | X1 | X2 | X3 | X4 | X5 | X6 | X1 | X2 | X3 | X4 | X5 | X6 |
| M1 | 18 | 3 | 3 | 12 | 4 | 60 | 1 | 0 | 0 | 0 | 0 | 0 | M12 | 8 | 8 | 8 | 12 | 4 | 60 | 0 | .5 | .5 | 0 | 0 | 0 |
| M2 | 8 | 13 | 3 | 12 | 4 | 60 | 0 | 1 | 0 | 0 | 0 | 0 | M13 | 8 | 8 | 3 | 17 | 4 | 60 | 0 | .5 | 0 | .5 | 0 | 0 |
| M3 | 8 | 3 | 13 | 12 | 4 | 60 | 0 | 0 | 1 | 0 | 0 | 0 | M14 | 8 | 8 | 3 | 12 | 9 | 60 | 0 | .5 | 0 | 0 | 5 | 0 |
| M4 | 8 | 3 | 3 | 22 | 4 | 60 | 0 | 0 | 0 | 1 | 0 | 0 | M15 | 8 | 8 | 3 | 12 | 4 | 65 | 0 | 5 | 0 | 0 | 0 | 5 |
| M5 | 8 | 3 | 3 | 12 | 14 | 60 | 0 | 0 | 0 | 0 | 1 | 0 | M16 | 8 | 3 | 8 | 17 | 4 | 60 | 0 | 0 | .5 | .5 | 0 | 0 |
| M6 | 8 | 3 | 3 | 12 | 4 | 70 | 0 | 0 | 0 | 0 | 0 | 1 | M17 | 8 | 3 | 8 | 12 | 9 | 60 | 0 | 0 | .5 | 0 | .5 | 0 |
| M7 | 13 | 8 | 3 | 12 | 4 | 60 | ,5 | ,5 | 0 | 0 | 0 | 0 | M18 | 8 | 3 | 8 | 12 | 4 | 65 | 0 | 0 | .5 | 0 | 0 | .5 |
| M8 | 13 | 3 | 8 | 12 | 4 | 60 | ,5 | 0 | ,5 | 0 | 0 | 0 | M19 | 8 | 3 | 3 | 17 | 9 | 60 | 0 | 0 | 0 | .5 | .5 | 0 |
| M9 | 13 | 3 | 3 | 17 | 4 | 60 | ,5 | 0 | 0 | ,5 | 0 | 0 | M20 | 8 | 3 | 3 | 17 | 4 | 65 | 0 | 0 | 0 | .5 | 0 | .5 |
| M10 | 13 | 3 | 3 | 12 | 9 | 60 | ,5 | 0 | 0 | 0 | ,5 | 0 | M21 | 8 | 3 | 3 | 12 | 9 | 65 | 0 | 0 | 0 | 0 | .5 | .5 |
| M11 | 13 | 3 | 3 | 12 | 4 | 65 | ,5 | 0 | 0 | 0 | 0 | ,5 | M R | 10 | 4 | 3 | 14 | 5 | 64 | .2 | .1 | 0 | .2 | .1 | .4 |

X1: Talc X2:Quartz X3: Limestone X4:Phyllit, X5:Dolomite X5:Clay Mx is the elaborated mass

## 3. Optimization and Discussion.

Table 2 shows the individual modeling of the response out for the quadratic model, where the determination coefficients $R^2$ evaluate if the equations obtained by regressions are representative. The effects of the interactions between raw materials are noticed.

Table 2 - Regression models obtained for the response Yi

| Variable of Response (Yi) | $R^2$ | model quadratic |
|---|---|---|
| Linear Retraction. (Y1) | 97% | Y1 = 3.26X1+ 2.42X2+ 1.1X3+ 3.23X4 + 1.48X5+ 3.07X6 – 1.79X1X3 – 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. |
| Bending Resistance. (Y2) | 76% | Y2=147X1+136X2+135X3+167X4+116X5+165X6+142X1X4+ 101X1X5+116X1X6-169X2X3+114X3X5+96X4X5+96X4X6+ 119X5X6. |
| Absorption of water (Y3) | 94,3% | Y3=13.12X1+17.35X2+20.65X3+15.85X4+22.27X5+15.5X6--- 5.15X1X2 –4.0X1X5+6.6X2X3-3.9X2X4 - 13.65X2X5–7.2X2X6– 10.75X4X5–5.20X4X6. |

Those equations show, for instance, that the quartz associated to the limestone reduces the linear retraction and the bending resistance simultaneously (-1.92 X2X3 and -169X2X3). In the production line, the minimum of linear retraction (minor is better) is important, but with the increase of the bending resistance (major is better). Having conflict is necessary, therefore, to find a conciliatory solution. The simultaneous study that leads the optimization of the response of interest is needed and will be the following subject.

**Optimization of the ceramic mass - The Function quality loss**

The best mass was selected among those presented at the planning matrix (table 1). We will use the loss function developed by Taguchi (Moorish end Taguhi, 1999; Bittencourt et all, 2001), and adapting it for our study. The illustrations 1 and 2 show 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 smallest losses lead the best mass (mass M19) in function of the best response.

Figure 1 compares two situations when it is sought responses of the type “minor is better.”

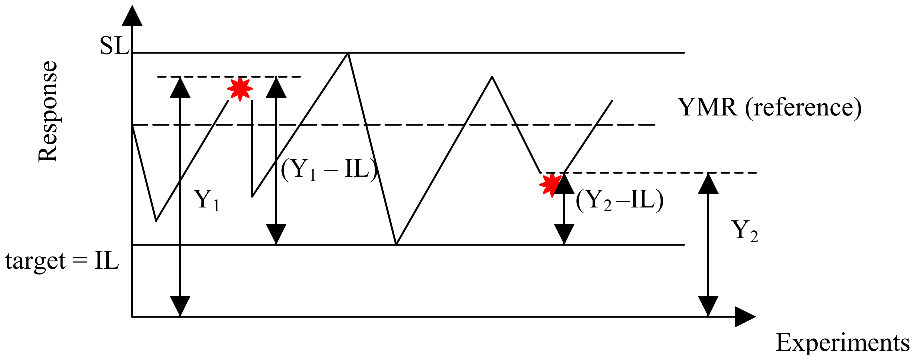


Figure 1 - Behavior of the graph for response of the type “smaller is better”

Where: IL = Inferior Limits = target: it is the value that would be ideal, (minor is better)
SL = Superior Limits, 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 observed that $Y_1 > Y_2$, whose situation is more favorable for Y2 (minor is better), and $(Y_1 - IL) > (Y_2 - IL)$ , what implicates in a larger loss for Y1 (worse response).

Equation 2 represents the evolution in the calculation of quality losses for ceramic mixtures starting from the discussion done based in figure 1.

$$\check{Z}(I) = \sum_{j=1}^{j} [1 / (SL - IL)^2 \text{ X } (R.I.) \text{ X } [(Y_J - IL_J)^2]] \quad (2)$$

(target=IL, the target value is the inferior limit)

R.I.: it is the relative importance (in weigh) of the responses. They are attributed to each one of the characteristics of qualities in agreement with the experience of the industrial engineers'.

For the cases of the type “major is better” (example: bending resistance), figure 2 shows the behavior of two responses, showing that the smallest losses happen when the largest response is obtained.

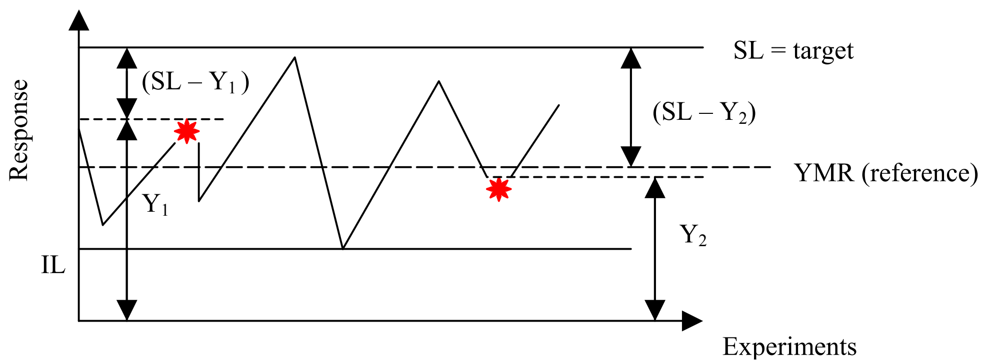


Figure 2 - Behavior of the graph for response of the major type is better

It is observed that $Y_1 > Y_2$, whose situation is more favorable for $Y_1$ (major is better), and $[SL - Y_1] < [SL - Y_2]$ implicates in a larger loss for $Y_2$.

In a similar way to the development of equation 2, the equation of the loss function in that situation (figure 2) is:

$$\check{Z}(I) = \sum_{j=1}^{j} [1 / (SL - IL)^2 \ \mathrm{x} \ (R.I.) \ X \ [(SL - Y_J)^2]] \qquad (3)$$

(target =SL , the target is the superior limit)

Table 3 shows the results of the loss of quality of the masses, using equations 2.e 3.

Table 3 - Summary of the Losses of Quality of the masses

| Mass | Loss Z R.L. | Loss Z W.A | Loss Z B.R. | **Loss Z Total** | Mass | Loss Z R.L. | Loss Z W..A | Loss Z B.R. | **Loss Z Total** |
|---|---|---|---|---|---|---|---|---|---|
| M1 | 2.24 | 0.00 | 0.68 | **2.92** | M12 | 0.04 | 2.83 | 5.05 | **7.92** |
| M2 | 0.82 | 0.89 | 1.10 | **2.81** | M13 | 0.86 | 0.31 | 0.47 | **1.02** |
| M3 | 0.00 | 2.83 | 2.29 | **5.12** | M14 | 0.18 | 0.54 | 1.40 | **2.12** |
| M4 | 2.19 | 0.37 | 0.47 | **3.03** | M15 | 1.53 | 0.11 | 0.88 | **2.53** |
| M5 | 0.08 | 4.19 | 3.08 | **7.35** | M16 | 0.22 | 1.67 | 0.41 | **2.30** |
| M6 | 1.80 | 0.28 | 0.45 | **2.53** | M17 | 0.20 | 2.85 | 0.94 | **3.99** |
| M7 | 1.59 | 0.03 | 1.90 | **3.53** | M18 | 0.20 | 1.23 | 0.20 | **1.63** |
| M8 | 0.25 | 0.77 | 0.83 | **1.85** | M19 | 0.29 | 0.00 | 0.29 | **0.58** |
| M9 | 2.19 | 0.04 | 0.01 | **2.24** | M20 | 2.77 | 0.08 | 0.00 | **2.85** |
| M10 | 0.56 | 0.64 | 0.43 | **1.63** | M21 | 0.86 | 1.29 | 0.01 | **2.26** |
| M11 | 2.09 | 0.01 | 0.09 | **2.19** | | | | | |

(R.L.: Linear Retraction W.A.: Water Absorption B.R.: Bending Resistance )

Larger Losses, in growing order:
M19 < M13 < M10 < M18.......... M19 is the best mass (smaller loss).
(0,58) (1,02) (1,63) (1,63)

Figure 3 shows the behavior of the masses in function to the quality losses.

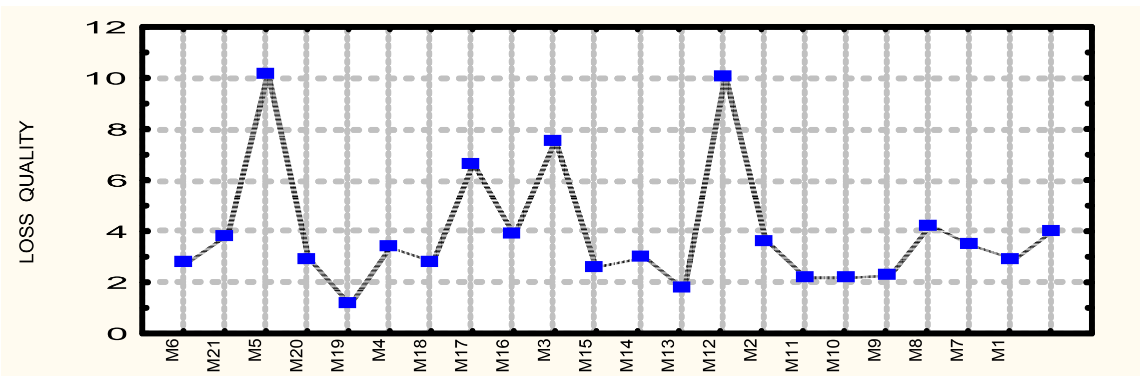


Figure 3 – Behavior of the losses of quality of the masses.

The model of optimization of the quality loss can be found in function of the independent variables Xi, because, Y=F(X) and Z=F(Y) → Z = F(X). The following expression represents the loss model Z(i) in function of the raw materials. Noticed in absolute terms, that the dolomite is the raw material that most contributes with the loss of quality of the masses (10.16 X5), and the clay tends to minimize the quality losses (2,82 X6). In relative terms, phyllite and dolomite minimize the quality loss (–2226X4X5):

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

Table 4 shows comparative data among the best mass selected between those elaborated at the planning matrix, through the function loss (mass M19); and the mass manufactured in the industry, the reference mass RM.

Table 4 - Comparison of the best masses, in relation to the reference mass RM.

| Mass A : Formulation (%wt) | | | | | | | B: codified Levels | | | | | | R.L | B.R | W.A. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass ↓ | X1 | X2 | X3 | X4 | X5 | X6 | X1 | X2 | X3 | X4 | X5 | X6 | | | |
| M | 10 | 4 | 3 | 14 | 5 | 64 | 0.2 | 0.1 | 0.0 | 0.2 | 0.1 | 0.4 | 2.7 | 172 | 14.7 |
| M19 | 8 | 3 | 3 | 17 | 9 | 60 | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 1.8 | 166 | 16.4 |

The mass M19 had presented a linear retraction around 50% smaller than the reference mass RM, without great changes in the bending resistance and water absorption. In terms of composition of the raw materials, that mass is characterized by a major percentile of phyllite and dolomite, compared with the reference mass RM.

## Conclusion

The use of the technique of experiments analysis was shown effective to the formulation of ceramic masses, because the studies allowed a better understanding of the influences of raw materials in the behavior of the response of the masses used in the industry. It can lead the improvement of the quality of the product, with less refuse and consequently with smaller production costs.

The equations of quality losses, developed in this work, allow to select the best mass among the several ones that are part of the planning matrix.

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