Taguchi design and flower pollination algorithm application to optimize the shrinkage of triaxial porcelain containing palm oil fuel ash

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Abstract. In the preparation of triaxial porcelain from Palm Oil Fuel Ash (POFA), a new parameter variable must be determined. The parameters involved are the particle size of POFA, percentage of POFA in triaxial porcelain composition, moulding pressure, sintering temperature and soaking time. Meanwhile, the shrinkage is the dependent variable. The optimization process was investigated using a hybrid Taguchi design and flower pollination algorithm (FPA). The interaction model of shrinkage was derived from regression analysis and found that the shrinkage is highly dependent on the sintering temperature followed by POFA composition, moulding pressure, POFA particle size and soaking time. The interaction between sintering temperature and soaking time highly affects the shrinkage. From the FPA process, targeted shrinkage approaching zero values were predicted for 142 µm particle sizes of POFA, 22.5 wt% of POFA, 3.4 tonne moulding pressure, 948.5 °C sintering temperature and 264 minutes soaking time.

Keywords: Triaxial porcelain; Palm Oil Fuel Ash; Shrinkage; Taguchi Design; Flower Pollination Algorithm

1. Introduction

Conventional triaxial porcelain body mixed contains three main components; plastic material, fluxing agent and filler. Usually the plastic material is kaolinite, the fluxing agent is feldspar and the filler is quartz. Formulations of triaxial porcelain (SiO2– Al2O3–KNaO) usually involve 25 wt.% of plastic component, 25 wt.% silica and 50 wt.% feldspar (generally sodium feldspar) for soft porcelain and 50 wt.% of clay, 25 wt.% silica and 25 wt.% feldspar (generally potassium feldspar) for hard porcelain[1,2]. Clay provides plasticity and green strength to the body and acts as a binder. Feldspar acts as a fluxing material which does mean that generates low melting phase and helps vitrification. Quartz is a filler material which remains stable in the normal firing range and reduces distortions and shrinkage[3]. Many studies on triaxial porcelains report that quartz significantly affects triaxial porcelain properties [4–6]. Recently, researchers were tried to replace those natural raw materials with a variety of industrial waste
materials. Furthermore, the fabrication of products of waste is an advantage that may give the manufacturer a highly competitive position in the market due to the economic issues involved. Blast furnace slag and coal fly ash are examples of waste material which has been converted into some raw material added in recent years [7–15].

Currently, Malaysia had large palm oil industry. Furthermore, Malaysia is the second largest global palm oil producer and exporter after Indonesia [16]. Palm oil industry had daily wastage of burning of empty fruit bunch, fiber and palm oil shell in the boiler. This wastage was called as POFA. Currently, POFA usage is very limited and uncontrollable, and most of it is disposed of towards landfills. Consequently, it has caused numerous environmental harms [17]. Earlier, POFA was applied for variety of application and typically used in concrete application. In concrete, POFA was used as filler to increase the strength of concrete [18]. Besides, POFA was used as pozzolanic material which can improve the durability of the concrete [19]. Previously, the potential of POFA in ceramic application was applied. POFA was heated at 600 °C at 1.5 hours to produce treated POFA (TPOFA). Their study consist of volume shrinkage, porosity, bulk density, bending strength and compressive strength [20]. The properties accomplished still track the standard requirement of porcelain products.

Shrinkage is the rate at which the body shrinks during drying and firing. In manufacturing process, the shrinkage is a great importance issues. It is broadly used in the control of the end product size. During the sintering process, the success of firing depends in control of shrinkage consequently. Currently, minimum shrinkage achieved is 18% with 2 wt% of TPOFA additive [20]. However, the shrinkage from blast furnace slag at present achieves value less than 1% for 6-13 wt % additive [10]. Sometimes, negative shrinkage was attained means that the specimen expanded upon sintering process. The negative shrinkage was observed after 1120 °C indicating initiating of over firing [21]. Overall, the approaching zero shrinkage must be targeted by researchers [22].

Various styles design of experiment (DOE) was applied to optimize the optimal parameter of triaxial porcelain process. The familiar DOE applied is the mixture design where it optimizes the best composition of three raw materials in form. Mixture design functional need fixed other processing parameters like sintering temperature and soaking time [23–27]. Earlier, Taguchi design was applied in investigation of high temperature co-fired ceramics sintering conditions. The investigation only ran nine experiments (L9 orthogonal array table) to discover the optimal peak temperature, dwell time and heating rate [28]. Recently, Taguchi design application constant the composition of all raw materials [28]. The Taguchi design also was compared with other DOE or statistical tools for validation purpose [29].

Taguchi design usually involve signal to noise ratio (S/N) analysis. The S/N ratio limited to recognize the optimum parameter directly from the list of variable in Taguchi design table. So, the researchers tried a lot of alternatives to develop the result precisely such as cuckoo search algorithm, FPA, swarm algorithm, genetic algorithm and others. FPA is proposed to this paper to solve the problem of optimal triaxial porcelain parameter. It has only one key parameter p (switch probability) which makes the algorithm easier to implement and faster to reach optimal solution. FPA originally created by Yang [30]. Nowadays, FPA is well-known for researchers to optimize several application problems.

In this investigation, shrinkage was studied on hard triaxial porcelain with mixed POFA as filler material. The Taguchi design through orthogonal array was applied upon study to design an experiment with minimum number of test. FPA was applied to determine the optimal variable of parameter to accomplish targeted shrinkage.

2. Experimental

2.1. Methods

Four main raw materials were prepared including kaolin, potash feldspar, quartz and POFA. The kaolin, potash feldspar and quartz were already comes in the form of fine powder. Kaolin was supplied by Kaolin (M) Sdn Bhd, Malaysia with grade KM40. Besides, potash feldspar and quartz was supplied from BG Oil Sdn Bhd, Malaysia. Meanwhile, POFA was supplied from Genting Ayer Hitam Oil Mill, Johor, Malaysia. It is originally supplied in form of large particles and impurities. POFA was sieve by
160 µm and 63 µm sieves to create the unground POFA (UPOFA) and ground POFA (GPOFA) respectively. Six different porcelain samples were prepared as per the batch composition provided in Table 1. The standard composition of hard porcelain denoted are 50 wt. % kaolin, 25 wt. % quartz and 25 wt. % potash feldspar [1,2].

| Batch  | Percentage composition of Raw Material (wt %) |
|--------|-----------------------------------------------|
|        | Kaolin | Potash Feldspar | Quartz | UPOFA | GPOFA |
| QU5    | 50     | 25              | 20     | 5     | 0     |
| QU15   | 50     | 25              | 10     | 15    | 0     |
| QU25   | 50     | 25              | 0      | 25    | 0     |
| QG5    | 50     | 25              | 20     | 0     | 5     |
| QG15   | 50     | 25              | 10     | 0     | 15    |
| QG25   | 50     | 25              | 0      | 0     | 25    |

All raw materials were mixed based on the percentage composition of variable POFA composition, 5-25 wt% as shown in Table 1. Six mixtures were prepared by using a FRITSCH’s planetary mono mill. Each mixing process in the machine was milled at 250RPM by 30 minutes. The dried mixture was compacted manually by using Carver Press. The compaction with variable pressure, 2-4 tonne based on Taguchi design in Table 2. The specimens are in the form of cylinder pellet of 13 mm in diameter with variable thickness, 3-4 mm. At least five compacted specimens were prepared for each similar experiment which need 5 × 18 = 90 specimens overall [31]. The compacted specimen was sintered in an electric furnace with variable temperature, 800-1200°C and variable soaking time, 60-300 minutes as shown in Table 2. Meanwhile, heating and cooling rate was fixed at 5 °C/min. The thickness and diameter of specimen before and after the sintering process was measured by using the Vernier caliper. The volume of specimens for both before and after the sintering process was calculated to determine the shrinkage of the specimen based on Eq. (1):

\[
\text{Shrinkage} = \frac{V_p - V_s}{V_p} \times 100
\]

where \(V_p\) and \(V_s\) are the specimen’s volume before and after sintered, respectively.

2.2. Taguchi design

The Taguchi method, developing the orthogonal arrays from experimental design theory to study a large number of variables with minor number of experiments, was chosen to optimize the preparation condition of triaxial porcelain from POFA. POFA particle size, POFA composition, moulding pressure, sintering temperature and soaking time were chosen as factors and an appropriate L18 orthogonal array with five factors at mixed level of two and three levels was selected to conduct the experiment as shown in Table 2.

Normally, a full factorial design would require \(2^3 \times 3^4 = 162\) experimental runs. Apparently, it is impossible to do these experimental runs and accompanies with very high cost, while with using Taguchi method simply 18 experiments are needed based on the L18 orthogonal array, as shown in Table 2. The parameter variables were normalized between (-1, 1) using Eq. (2) in order to ascertain the direct comparison of the observations from different scales, and thus the individual influence of each parameter in characterizing the output response can be explored:

\[
X_n = 2 \frac{X - \bar{X}}{X_{max} - X_{min}}
\]
where $X_n$ is the normalized value of the parameter variables POFA particle size, POFA composition, moulding pressure, sintering temperature and soaking time, $X$ is the absolute value of the actual response, $\bar{X}$ is the mean value of $X_{max}$ and $X_{min}$ whereas $X_{max}$ and $X_{min}$ is the maximum and minimum value for a particular parameter variable, respectively. The normalized result was shown in Table 2.

Table 2: Taguchi L18 and Experimental Results

| No. | Parameters | Actual value | Coded value | Experimental values for shrinkage (%) |
|-----|------------|--------------|-------------|---------------------------------------|
|     |            | POFA Particle Size (µm) | POFA Composition (Wt %) | Molding Pressure (Ton) | Sintering Temperature (°C) | Soaking Time (Minutes) | $X_A$ | $X_B$ | $X_C$ | $X_D$ | $X_E$ | |
| 1   | 160        | 5            | 2           | 800         | 60         | 1                | 17.62 | 14.80 | 22.27 |
| 2   | 160        | 5            | 3           | 1000        | 180        | -1               | 1      | 0     | 15.82 |
| 3   | 160        | 5            | 4           | 1200        | 300        | -1               | -1     | -1    | 17.88 |
| 4   | 160        | 15           | 2           | 800         | 180        | -1               | 0      | -1    | 6.25  |
| 5   | 160        | 15           | 3           | 1000        | 300        | -1               | 0      | 0     | 3.79  |
| 6   | 160        | 15           | 4           | 1200        | 60         | -1               | 0      | 1     | 16.51 |
| 7   | 160        | 25           | 2           | 1000        | 60         | -1               | 1      | 0     | 2.05  |
| 8   | 160        | 25           | 3           | 1200        | 180        | -1               | 1      | 0     | 9.59  |
| 9   | 160        | 25           | 4           | 800         | 300        | -1               | 1      | 1     | -3.32 |
| 10  | 63         | 5            | 2           | 1200        | 300        | 1                | -1     | -1    | 22.27 |
| 11  | 63         | 5            | 3           | 800         | 60         | 1                | -1     | 0     | -1.32 |
| 12  | 63         | 5            | 4           | 1000        | 180        | 1                | 1      | 0     | 14.80 |
| 13  | 63         | 15           | 2           | 1000        | 300        | 1                | 0      | -1    | 2.31  |
| 14  | 63         | 15           | 3           | 1200        | 60         | 1                | 0      | 0     | 17.62 |
| 15  | 63         | 15           | 4           | 800         | 180        | 1                | 0      | 1     | -8.76 |
| 16  | 63         | 25           | 2           | 1200        | 180        | 1                | 1      | -1    | 24.08 |
| 17  | 63         | 25           | 3           | 800         | 300        | 1                | 1      | 0     | -2.97 |
| 18  | 63         | 25           | 4           | 1000        | 60         | 1                | 1      | 0     | -4.76 |

2.3. Flower pollination algorithm
The coded values of the experimental results were then modeled with the following interaction model equation (Eq. (3)).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i<j}^{k} \beta_{ij} X_i X_j$$  

where $Y$ is the dependent variable or estimation for the response variables of the designed experiment (shrinkage), $k$ is the number of normalized parameter variables (where $k = 5$ in this study), and $\beta$ is the estimation for the regression coefficient computed by least squares approach. The $X_i X_j$ term in this equation account for two variable interaction effects of the parameter variables with the response variables, shrinkage.

Interpolation on the relationship of the parameter variables and the dependent response variables will be examined by using the FPA [30]. The pseudo code of the FPA applied in Matlab software was shown in Figure 1.

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Flower Pollination Algorithm (or simply Flower Algorithm)

Objective min or max $f(x), x = (x_1, x_2, ..., x_d)$

Initialize a population of n flowers/pollen gametes with random solutions

Find the best solution $g_\ast$ in the initial solution

Define a switch probability $p \in [0,1]$.  

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4
Define a stopping criterion (either a fixed number of generations/iterations or accuracy) while \( t < \text{MaxGeneration} \)

\[
\text{for } i = 1: n \text{ (all n flowers in the population)} \\
\quad \text{if } \text{rand} < p, \\
\quad \quad \text{Draw a (d-dimensional step vector } L \text{ which obeys a Levy distribution} \\
\quad \quad \text{Global pollination via } x_i^{t+1} = x_i^t + L(g^* - x_i^t) \\
\quad \text{else} \\
\quad \quad \text{Draw } c \text{ from a uniform distribution in } [0,1] \\
\quad \quad \text{Do local pollination via } x_i^{t+1} = x_i^t + c(x_j^t - x_k^t) \\
\text{end if} \\
\text{Evaluate new solutions} \\
\text{If new solutions are better, update them in the population} \\
\text{end for} \\
\text{Find the current best solution } g^* \\
\text{end while} \\
\]

Output the best solution found

**Figure 1:** Pseudo code of the proposed Flower Pollination Algorithm (FPA) [30]

By setting the population size 25 and total number of iteration 5000, the coding was run to develop the best result of targeted shrinkage value.

3. Result and discussion

3.1. Interaction modelling

Table 3 presents the regression statistics result, which R square equal to 0.98, which is a very good fit. The 98% of the variation in shrinkage is explained by all independent variables investigated. The closer to 1, the better the regression line fits the data. Meanwhile, from the analysis of variance (ANOVA) (Table 4) the result are statistically insignificant due to significant F value greater than 0.05. In addition, all variables are statistically insignificant to the shrinkage due to all P value greater than 0.05. But, the investigations still consider all variables in modelling equation. The sign and magnitude of regression coefficient signify the relative influence of each parameter on the output response (shrinkage) with a negative sign indicating an antagonistic effect whilst a positive one signifies a synergistic effect (Table 5). The mathematical interaction model of shrinkage was developed based on the sign and magnitude of regression coefficient as shown in Eq. (4).

| Table 3: Regression Statistics |
|--------------------------------|
| Regression Statistics          |
| Multiple R (Correlation coefficient) | 0.976345669 |
| R Square (Coefficient of determination) | 0.953250865 |
| Adjusted R Square              | 0.602632353 |
| Standard Error                 | 6.566039377 |
| Observation                    | 18          |

| Table 4: ANOVA |
|----------------|
| df  | SS   | MS   | F    | Significance F |
|-----|------|------|------|----------------|
| Regression | 15   | 1758.209371 | 117.2139581 | 2.718769352 | 0.301680675 |
| Residual    | 2    | 86.22574619 | 43.1128731  |                |              |
| Total       | 17   | 1844.435117 |                   |                |              |

| Table 5: Coefficient of mathematical interaction model |
|-------------------------------------------------------|
| Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% |
|---------------|----------------|--------|---------|-----------|-----------|
| Intercept     | 7.01           | 1.54763 | 4.53264 | 0.04539   | 0.35594   | 13.67377 |
| X_A           | 0.44           | 2.26297 | 0.19454 | 0.86372   | -9.29652  | 10.17700 |
| X_B           | -3.86          | 2.74290 | -1.40841| 0.29435   | -15.66486 | 7.93863  |
The present study deals with experimental investigation in triaxial porcelain preparation containing waste material POFA. The experiment has been carried out based on Taguchi L18 orthogonal array and the response surface methodology (RSM).

3.1. Shrinkage

Shrinkage is highly dependent on the sintering temperature (X_D), as shown in Eq. (4), followed by POFA composition (X_B), moulding pressure (X_C), POFA particle size (X_A) and soaking time (X_E). In terms of parameter variable interaction, shrinkage is highly dependent on the interaction X_D X_E (sintering temperature and soaking time) followed by X_C X_D (moulding pressure and sintering temperature), X_A X_D (POFA particle size and sintering temperature), X_B X_C (POFA composition and moulding pressure), X_B X_E (POFA composition and soaking time), X_C X_E (moulding pressure and sintering temperature), X_A X_E (POFA particle size and soaking time), X_B (POFA composition and sintering temperature) and X_A X_C (POFA particle size and moulding pressure).

The FPA gives the best solution for approaching zero shrinkage as follow: 142 µm POFA particle size; 22.5 wt% of POFA composition; 3.4 tonne Carver moulding pressure; 948.5 °C sintering temperature and 264 minutes soaking time. Besides, the FPA also can generate other results as shown in Table 6.

\[
\text{Shrinkage} = 7.01 + 0.44X_A - 3.86X_B + 1.37X_C + 9.73X_D + 0.03X_E + 0.88X_A X_B - 0.37X_A X_C + 2.4X_A X_D + 0.71X_A X_E - 2.06X_B X_C - 0.44X_B X_D - 2X_B X_E - 1.89X_C X_D - 2.67X_C X_E + 3.11X_D X_E
\]

(4)

| No | Parameter | PFOA size (µm) | PFOA Composition (wt %) | Molding Pressure (Tonne) | Sintering Temperature (°C) | Soaking Time (min) | Shrinkage (%) |
|----|-----------|----------------|-------------------------|-------------------------|---------------------------|-------------------|---------------|
| 1  | 90        | 21.3           | 2.0                     | 925.5                   | 298                       | 0.031             |
| 2  | 134       | 9.2            | 2.0                     | 946.8                   | 60                        | 0.005             |
| 3  | 146       | 19.9           | 2.3                     | 911.8                   | 122                       | 0.015             |
| 4  | 159       | 24.4           | 2.7                     | 932.6                   | 162                       | 0.047             |
| 5  | 68        | 17.1           | 2.0                     | 912.4                   | 63                        | 0.002             |
| 6  | 63        | 7.6            | 2.0                     | 876.3                   | 109                       | 0.023             |
| 7  | 143       | 12.5           | 2.1                     | 932.8                   | 60                        | 0.039             |
| 8  | 116       | 15.8           | 2.0                     | 932.8                   | 60                        | 0.054             |
| 9  | 83        | 24.8           | 2.1                     | 922.8                   | 84                        | 0.065             |
| 10 | 79        | 25.0           | 4.0                     | 1072.1                  | 300                       | 0.030             |

4. Conclusions

The present study deals with experimental investigation in triaxial porcelain preparation containing waste material POFA. The experiment has been carried out based on Taguchi L18 orthogonal array and
optimized the process parameters for targeted shrinkage. Mathematical interaction model of shrinkage in terms of all parameter variables have been developed using regression analysis and checked for its adequacy. The model developed was inserted into FPA command in Matlab software to develop the best optimal parameter variable for targeted shrinkage. The following conclusions may be drawn from the results of this investigation.

- From mathematical intersection model, the shrinkage is highly dependent on the sintering temperature followed by POFA composition, moulding pressure, POFA particle size and soaking time.
- In terms of interaction between two parameters, the shrinkage is highly dependent on interaction \( X_{DE} \) (sintering temperature and soaking time) followed by \( X_{CE} \) (moulding pressure and soaking time), \( X_{AD} \) (POFA particle size and sintering temperature), \( X_{BC} \) (POFA composition and moulding pressure), \( X_{BD} \) (POFA composition and sintering temperature), \( X_{AE} \) (POFA particle size and soaking time), \( X_{BE} \) (POFA composition and soaking time), \( X_{AD} \) (POFA particle size and moulding pressure).
- To achieve approaching zero shrinkage is as follow: 142 µm POFA particle size; 22.5 wt% of POFA composition; 3.4 tonne Carver moulding pressure; 948.5 °C sintering temperature and 264 minutes soaking time.
- The optimal parameter variable listed limited for the single objective only: approaching zero shrinkage.

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References
[1] E. Kamseu, C. Leonelli, D.N. Boccaccini, P. Veronesi, P. Miselli, G. Pellacani, U. Chinje Melo., Characterisation of porcelain compositions using two china clays from Cameroon, Ceramics International. 33 (2007) 851–857.
[2] H. Boussak, H. Chemani, A. Serier, Characterization of porcelain tableware formulation containing bentonite clay, International Journal of Physical Sciences. 10 (2015) 38–45.
[3] W.M. Cam, U. Senapati, Porcelain-Raw Materials, Processing, Phase Evolution, and Mechanical Behavior, Jornal of the American Ceramic Society. 81 (1998) 3–20.
[4] A.D.N. Junior, D. Hotza, V.C. Soler, E.S. Vilches, Effect of quartz particle size on the mechanical behaviour of porcelain tile subjected to different cooling rates, Journal of the European Ceramic Society. 29 (2009) 1039–1046.
[5] G. Stathis, A. Ekonomakou, C.J. Stournaras, C. Ftikos, Effect of firing conditions, filler grain size and quartz content on bending strength and physical properties of sanitaryware porcelain, Journal of the European Ceramic Society. 24 (2004) 2357–2366.
[6] S.I. Warshaw, R. Seider, Comparison of Strength of Triaxial Porcelains Containing Alumina and Silica, Journal of the American Ceramic Society. 50 (1967) 337–343.
[7] K. Dana, S.K. Das, Partial substitution of feldspar by B.F. slag in triaxial porcelain: Phase and microstructural evolution, Journal of the European Ceramic Society. 24 (2004) 3833–3839.
[8] E. Karamanova, G. Avdeev, A. Karamanov, Ceramics from blast furnace slag, kaolin and quartz, Journal of the European Ceramic Society. 31 (2011) 989–998.
[9] I. Ozdemir, S. Yilmaz, Processing of unglazed ceramic tiles from blast furnace slag, Journal of Materials Processing Technology. 183 (2007) 13–17.
[10] Z. Bayer Ozturk, E. Eren Gultekin, Preparation of ceramic wall tiling derived from blast furnace slag, Ceramics International. 41 (2015) 12020–12026.
[11] S. Ghosh, M. Das, S. Chakrabarti, S. Ghatak, Development of ceramic tiles from common clay and blast furnace slag, Ceramics International. 28 (2002) 393–400.
[12] A. Zimmer, C.P. Bergmann, Fly ash of mineral coal as ceramic tiles raw material., Waste Management (New York, N.Y.). 27 (2007) 59–68.
[13] K. Dana, S. Das, S.K. Das, Effect of substitution of fly ash for quartz in triaxial kaolin–quartz–feldspar system, Journal of the European Ceramic Society. 24 (2004) 3169–3175.

[14] A. Olgun, Y. Erdogan, Y. Ayhan, B. Zeybek, Development of ceramic tiles from coal fly ash and tincal ore waste, Ceramics International. 31 (2005) 153–158.

[15] M. Aineto, A. Acosta, I. Iglesias, The role of a coal gasification fly ash as clay additive in building ceramic, Journal of the European Ceramic Society. 26 (2006) 3783–3787.

[16] MPOB, Overview of the Malaysian Oil Palm Industry 2015, Malaysia Palm Oil Board. (2016). http://www.mpob.gov.my/ (accessed September 20, 2016).

[17] E. Khankhaje, M.W. Hussin, J. Mirza, M. Rafieizonooz, M.R. Salim, H.C. Siong, M. Naqiuddin M. Warid, On blended cement and geopolymer concretes containing palm oil fuel ash, Materials & Design. 89 (2015) 385–398.

[18] S.K. Lim, C.S. Tan, O.Y. Lim, Y.L. Lee, Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler, Construction and Building Materials. 46 (2013) 39–47.

[19] W. Kroehong, T. Sinsiri, C. Jaturapitakkul, Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste, Procedia Engineering. 14 (2011) 361–369.

[20] J. Usman, M. Zaky, Z. Ariffin, Effects of palm oil fuel ash composition on the properties and morphology of porcelain-palm oil fuel ash composite, Jurnal Teknologi (Sciences & Engineering). 70 (2014) 5–10.

[21] E. Rambaldi, W.M. Carty, A. Tucci, L. Esposito, Using waste glass as a partial flux substitution and pyroplastic deformation of a porcelain stoneware tile body, Ceramics International. 33 (2007) 727–733.

[22] S. Salem, A. Salem, Shrinkage prediction during non-isothermal sintering in the presence liquid phase: New kinetic model, Part I, Thermochimica Acta. 575 (2014) 322–330. doi:10.1016/j.tca.2013.11.004.

[23] B.K. Ngun, H. Mohamad, K. Katsumata, K. Okada, Z.A. Ahmad, Using design of mixture experiments to optimize triaxial ceramic tile compositions incorporating Cambodian clays, Applied Clay Science. 87 (2014) 97–107.

[24] S. Correia, D. Hotza, A. Segadães, Simultaneous optimization of linear firing shrinkage and water absorption of triaxial ceramic bodies using experiments design, Ceramics International. 30 (2004) 917–922.

[25] S.L. Correia, K.A.S. Curto, D. Hotza, A.M. Segadães, Using statistical techniques to model the flexural strength of dried triaxial ceramic bodies, Journal of the European Ceramic Society. 24 (2004) 2813–2818.

[26] S.L. Correia, G. Dienstmann, M. V Folgueras, A.M. Segadaes, Effect of quartz sand replacement by agate rejects in triaxial porcelain., Journal of Hazardous Materials. 163 (2009) 315–22.

[27] M. Dal Bó, A.M. Bernardin, D. Hotza, Formulation of ceramic engobes with recycled glass using mixture design, Journal of Cleaner Production. 69 (2014) 243–249.

[28] D. Jurków, J. Stiernstedt, Investigation of High Temperature Co-fired Ceramics sintering conditions using Taguchi Design of the experiment, Ceramics International. 40 (2014) 10447–10455.

[29] M.-L. Huang, Y.-H. Hung, Z.-S. Yang, Validation of a method using Taguchi, response surface, neural network, and genetic algorithm, Measurement. 94 (2016) 284–294.

[30] X. Yang, Flower Pollination Algorithm for Global Optimization, Unconventional Computation and Natural Computation 2012, Lecture Notes in Computer Science. 7445 (2012) 240–249.

[31] ASTM C326, Standard Test Method for Drying and Firing Shrinkages of Ceramic Whiteware Clays, ASTM International. (1982).