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Development of Standard Formulations for Porcelain Production from Ohiya Clay

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Abstract:

Optimal products design for producing standard ceramic porcelain products from Ohiya clay was determined in this study using desirability function analysis. Results revealed that the alumino-silicate constitutes 91% of the total mineralogical composition of Ohiya clay and 42:32:20 at a firing temperature of 1250/1300 ºC; 42:33:17 at a firing temperature of 1300 ºC; 41:32:27 at a firing temperature of 1000 ºC as the optimal mix of the clay, feldspar and silica for producing standard low/high voltage insulators, tiles and tablewares respectively. The production of the 11 kV electric insulator, 400×400 mm tile, serving dish at optimal settings are respectively six hundred and twenty-five naira (₦625), three hundred and twenty-two naira (₦322), three hundred and four seven (₦347) against the market prices of one thousand naira (₦1000), three hundred and fifty naira (₦350), four hundred and twenty naira (₦420) respectively. This translates to 60 %, 9 % and 21 % in profit for these products. Hence, adoption of the optimal mixing ratio as well as exploitation of this natural resource is highly recommended.

Keyword: *Porcelain Products, performance parameters, investor' interest, Ohiya clay, standard formulation*

1 Introduction

Clay is defined as earth or soil that is plastic and tenacious when moist and that becomes permanently hard when baked or fired [1]. It is also described as a fine-grained natural rock or soil material that combines one or more minerals with traces of metal oxides and organic matter [2-6]. According to a report by [7], clay is formed due to the decomposition of an igneous rock by some geologic hypogenic actions that result from the mixture of gases and vapour in the interior of the earth's crust over a very long period which must be about some million years ago. Thus, Clay consists of hydrous alumino-silicate minerals formed by the weathering of feldspathic rocks, such as granite [8].

Clays vary in plasticity, all being more or less malleable and capable of being moulded into any form when moistened with water. They are used for making various kinds of pottery, tobacco pipes, bricks and tiles etc. The commoner varieties of clay and clay rocks are china clay, kaolin, pipe clay, potter's clay, sculptor's clay, brick clay and fireclay [9]. The application of clay-based ceramics to mankind is important [10]. Ceramic applications of clay materials include but not limited to bricks, fireclay refractories, earthenware, stoneware, porcelain, sanitary ware and tableware [11-13]. Apart from serving the immediate needs of man such as household utensils and decorative tableware [14], it is also applied in various other diverse ways to satisfy the demands of mankind.

In this research, ceramic applications of clay materials in industrial production of ceramic porcelain products were undertaken. These products include electric insulators, tableware and tiles. For technical purposes, porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares [15]. Porcelain is an inorganic compound made by heating a blend of Kaolin, Quartz and Feldspar, each of which reacts when subjected to appropriate heat temperature [16,10]. Kaolin serves as the plastic material while quartz (silica) and feldspar are the non-plastic materials. When fired, porcelain (made of a clayey body) becomes very hard, strong and translucent (when glazed) though unreactive and containing little or no iron impurities [10].

Porcelain insulators are used in electrical power transmission system due to their high electrical, mechanical and thermal properties [17]. These are the reasons for their continued use over the years despite the emergence of new materials like plastics and composites [18]. Clay-based porcelain insulators are the commonly used ceramic insulators for both low and high tension insulation and they are considered as one of the most complex ceramic materials [18]. For electrical insulation applications, porcelains are expected to meet minimum specifications values of 16 kV/mm and 69 MPa for dielectric strength and modulus of rupture, respectively [15].

Furthermore, tiles and tablewares are also categorized as porcelain products. Tiles are used for interior and exterior decoration and they belong to a class of ceramics known as white wares. The raw materials used to form tile consist of clay minerals, natural minerals and chemical additives. These minerals and additives are often refined or beneficiated and they are required for the shaping process and used to lower the firing temperature. Ceramic tiles are consumed in bulk by their single largest end-user i.e. the construction industry and the constituent raw materials are classified by their particle size. For many ceramic products, including tile, the body composition is determined by the amount and type of raw materials. Therefore, it is important to mix the right amounts together to achieve the desired properties. Continuing, tableware is the dishes or dishware used for setting a table, serving food and dining. It includes cutlery, glassware, serving dishes and other useful items for practical as well as decorative purposes [19].

Despite the extensive research in the use of clay deposits from other parts of the country, it is clear that the study of Ohiya clay which is rich in kaolinite with a kaolin deposit bulk reserve of about 74.38 million metric tonnes [25] is undermined partly due to its location in the country or ignorance of its potentials. Efforts have been made in the use of this abundant clay in refractory applications and palm kernel bleaching [25-27] but other ceramic applications of these clay deposits have not been well explored. Even with its study for refractory applications, its optimal mix for various ceramic applications is yet to be established, thereby making it difficult for potential investors to access valid information about this abundant natural resource at Ohiya.

Hence, this study applied RSM –based desirability function analysis to establish mathematical models and optimal framework for composing Ohiya clay and additives into various ceramic porcelain products. Thus making its overall production cost to be low and thus attract investors to this sector.

2 Materials and Methods

The clay sample was sourced from Ohiya clay deposit in Umuahia South LGA of Abia State, Nigeria. Preparation/production of test specimens for the analysis of Ohiya clay and ceramic porcelain products from it was done at Project Development Institute (PRODA) Enugu, Enugu State, Nigeria. The silica and feldspar used in this study were sourced from Ishiagu in Ebonyi State, Nigeria.

The clay sample obtained from Ohiya was analysed to determine its mineralogical and chemical composition using the X-ray diffraction (XRD) and X-ray fluorescence (XRF) machines. The XRD analysis was done at Nigeria Geological Laboratory Zaria, Kaduna State, Nigeria while the XRF analysis was done at Central laboratory Ahmadu Bello University, Zaria, Kaduna State, Nigeria. A sample of 200 g of the Ohiya clay was crushed and milled to a fine particle. The mineral phases within the sample were identified by powdered X-ray diffractometry method. The sample was first subjected to X-ray scanning using the Philips PW 1830 X-ray diffractometer with a Cu-anode. After the X-ray scanning of the sample, mineral peaks were identified using XPert High Score plus Software. The background and peak-positions were identified and based on the peak positions and intensities, a search-match routine was performed and mineralogical composition of the clay was determined.

Quantitative analysis of chemical composition of the sample was also done by X-ray Fluorescence Spectroscopy using a Magi X Pro XRF Spectrometer. For this purpose, 200 g of the powdered clay sample was mixed with Herzog organic binder. The organic binder contained cellulose and wax. The mixture was homogenized by milling. The homogenized sample was placed in an aluminium cup and hydraulically pressed into pellets. This was done to ensure sample integrity under the vacuum and a consistent surface to receive the X-rays.

2.1 Production of Porcelain Electric Insulators and Tablewares

The lumps of Ohiya clay were crushed using a clay crushing mill, sun-dried, and granulated using a pan mill, and also sieved through 0.425 mm sieve. The porcelain body was formulated using the optimal mixing ratio for clay, feldspar and silica in wt % of 42:32:20 respectively, at a firing temperature of 1250 ^{o}C as shown in the desirability plot (Fig. 1). Porcelain insulator bodies (for the low and high voltage each respectively) were formulated in accordance with weight percentage obtained in desirability plot, and placed in the porcelain moulds using a process known as slip casting. Square mould of 80 mm X 80 mm X 80 mm. was produced with plaster of Paris (POP) and the setup was left for two days to air dry and this was followed by Bisque firing in a gas-fired kiln at the rate of 150 ^{o}C/hr before glaze and vitrification was applied to each sample at the optimal temperature of 1200 ^{o}C. This process was followed by firing and thereafter experimental validation of the optimal settings of insulation resistance, polarization index and dielectric testing of the samples were carried out, [15]. Similar process was adopted for the production of the Tableware. This was done at the optimal mixing ratio for clay, feldspar and silica in wt % is 41:32:27 at a firing temperature of 1000 ^{o}C.

2.2 Production of Tile

The mixture of clay, feldspar and silica was made using the optimal weight percent obtained from desirability plot. The clay body of 8 kg was milled and mixed with 1litre of water to form a slurry. Excess water was removed using the hydraulic filter press followed by spray drying. The dry powder obtained after spray drying was placed into tile moulds. The formulated body of the tile was pressed to the size and shape of the mould before drying. Heat was applied to the tiles by convection using hot gases from the furnace. After drying, the tiles entered a temporary storage facility known as the racking and deracking chamber. This chamber aids in removing excess moisture, it presents and stabilizes the quality of the product before glazing. The firing of the tiles was carried out in a furnace at the vitrification temperature of 1300°C as obtained in the desirability plot for experimental evaluation.

2.3 Optimization and Performance Test Procedure

Optimization was performed using optimization tools of version 17 of MINITAB to ensure the accuracy of the results. The optimization graphs were generated per factor pair per response with exploration data tips. The data tips of the graphs are the optimization tool used for exploring the critical (optimal) factor levels that yields maximum possible values of the products performance parameters of Modulus of rapture (H), Apparent density (D_A), cold compression strength (CCS) or the minimum values of the apparent porosity (P_a), water absorption rate (W) and linear shrinkage (L_s)in the plots. The optimal mix ratio for the clay, feldspar and silica at the optimal firing settings obtained from desirability function analysis was used in the clayey body formulations for the ceramic porcelain products.

The actual low and high levels of the factors were determined from experiments required for the empirical analysis of the ceramic properties of Ohiya clay using the equations 1 to 4 to effect the coding and are tabulated in table 2.

$$x_1 = \frac{Q_c - 35}{15} \qquad 1$$

$$x_2 = \frac{Q_f - 17.5}{7.5} \qquad 2$$

$$x_3 = \frac{T-1125}{125} \quad 3$$

$$x_4 = \frac{Q_S-25}{15} \quad 4$$

Where Q_c is quantity of clay (wt %); Q_f is quantity of feldspar (wt %); T is temperature (^oc) and Q_s is quantity of silica (wt %).

In addition, the dielectric strength test for the insulator was done at Enugu Electricity Distribution Company (EEDC), Umuahia, Abia State, Nigeria according to [15]. An insulation tester with model number "Fluke 1550c/1555" and rated capacity of 5000 volts was used in determining the insulation resistance of the porcelain insulator samples. The live and earth props were connected to the respective ports in the tester and the tester was switched on. The other end of the props were connected to the insulator material. For the insulation resistance test, the timer was set to sixty seconds (60 seconds) and the injected voltage was varied from 250 volts to 5000 volts. Values of the insulation resistance at the end of the timer countdown for each injected voltage was digitally displayed by the instrument and recorded. The polarization index of the insulator was determined by setting the timer to 10 minutes and injected voltage kept constant at 5000 volts. Values of the resistance obtained at the end of every one minute were recorded and the polarization index was calculated using equation 5 [15].

$$Polarization\ index = \frac{Resistance\ at\ the\ 10th\ minute}{Resistance\ at\ the\ 1st\ minute} \quad 5$$

3 Results and Discussion

Table 1 shows that the alumina-silicate oxides content of the clay constitute about 81 % of the total chemical composition of the clay. There are also traces of other chemical oxides like manganese, chromium, zinc, potassium, phosphorus, sodium, magnesium, calcium, titanium and iron. Hence, Ohiya clay is rich in alumina-silicate and hence suitable for ceramic porcelain products applications.

Table 1: Chemical Composition of Ohiya clay

S/N	Element	Concentration (Wt. %)
1	Na_2O	0.280
2	Mg_2O	1.340
3	Al_2O_3	32.160
4	SiO_2	49.02
5	P_2O_5	0.319
6	SO_3	0.303
7	Cl	0.004
8	K_2O	1.970
9	CaO	0.220
10	TiO_2	0.798
11	Cr_2O_3	0.029
12	Mn_2O_3	0.007
13	Fe_2O_3	0.970
14	ZnO	0.005
15	SrO	0.025
16	H_2O	12.550

Table 2 showed the actual low and high levels of the independent factors required for the empirical analysis of the ceramic properties/performance parameters of product mix. These are the limits used in variation of quantity of Ohiya clay, feldspar, temperature and silica to ascertain how significantly they affect apparent porosity(%), linear shrinkage(%), apparent density(g/cm^3), water absorption rate(%), cold compression strength (MPa) and rupture modulus(Kg/cm^2) of the ceramic products.

Table 2: Limits of the operational parameters

S/N	Factor Description	Coded Symbols	Factor Values	
			Low (-1)	High (+1)
1	Quantity of clay (wt %)	x_1	20	50
2	Quantity of feldspar (wt %)	x_2	10	25
3	Temperature (^oc)	x_3	1000	1250
4	Quantity of silica (wt %)	x_4	10	40

A two level single replicate, single block completely randomized full central composite design with six centre points and four factors shown in table 3 is the randomised design table comprising the coded factor values.

Table 3: Response Surface Design layout showing coded factors

Experimental Runs		Coded Values of Factors			
Std Order	Run Order	X_1	X_2	X_2	X_4
27	1	0	0	0	0
5	2	-1	-1	1	-1
30	3	0	0	0	0
25	4	0	0	0	0
17	5	-2	0	0	0
19	6	0	-2	0	0
14	7	1	-1	1	1
1	8	-1	-1	-1	-1
3	9	-1	1	-1	-1
18	10	2	0	0	0
24	11	0	0	0	2
23	12	0	0	0	-2
29	13	0	0	0	0
13	14	-1	-1	1	1
2	15	1	-1	-1	-1
6	16	1	-1	1	-1
22	17	0	0	2	0
9	18	-1	-1	-1	1
20	19	0	2	0	0
21	20	0	0	-2	0
7	21	-1	1	1	-1
10	22	1	-1	-1	1
26	23	0	0	0	0
8	24	1	1	1	-1
12	25	1	1	-1	1
16	26	1	1	1	1
11	27	-1	1	-1	1
4	28	1	1	-1	-1
15	29	-1	1	1	1
28	30	0	0	0	0

The reduced empirical relationships between the factors and responses developed and analysed using the MINITAB 17 are shown in equations 6 to 11 in coded units. The dependent variables are defined as modulus of rapture (H), apparent density (D_A), cold compression strength (CCS), the minimum values of the apparent porosity (P_a), water absorption rate (W) and linear shrinkage(L_s).

$$Pa = 13.4464 + 0.00458\, x_1 - 0.55125\, x_2 - 0.33125\, x_3 + 0.12208\, x_4 + 0.01201\, x_1^2 - 0.01188\, x_1 x_3 - 0.60812 x_1 x_4 + 0.51437\, x_3 x_4 \tag{6}$$

$$DA = 2.15167 - 0.045417\, x_1 + 0.079583\, x_2 + 0.018750\, x_3 + 0.023750\, x_4 + 0.009688\, x_1^2 + 0.012188\, x_2^2 + 0.038437\, x_3^2 + 0.007188\, x_4^2 + 0.024375\, x_1 x_2 + 0.019375\, x_1 x_3 + 0.040625\, x_1 x_4 + 0.049375\, x_2 x_3 - 0.041875\, x_2 x_4 + 0.123125\, x_3 x_4 \tag{7}$$

$$W = 6.6900 - 0.26313\, x_1 + 0.07187\, x_2 - 0.57187\, x_3 - 0.18729\, x_4 + 0.15401\, x_1^2 - 0.12849\, x_2^2 + 0.38526\, x_3^2 - 0.00849\, x_4^2 + 0.12281\, x_1 x_2 + 0.04094\, x_1 x_3 - 0.28344\, x_1 x_4 - 0.08656\, x_2 x_3 + 0.10406\, x_2 x_4 - 0.09031\, x_3 x_4 \tag{8}$$

$$Ls = 8.5513 + 2.3117\, x_1 - 0.2917\, x_2 + 2.5542\, x_3 + 0.3000\, x_4 + 0.1000\, x_1 x_4 - 0.0675\, x_2 x_3 - 0.0550\, x_3 x_4 \tag{9}$$

$$H = 36.1367 - 1.967\, x_1 + 2.233\, x_2 + 4.308\, x_3 + 0.150\, x_4 - 0.787\, x_2 x_3 + 0.775\, x_2 x_4 - 0.687\, x_3 x_4 \tag{10}$$

$$CCS = 20.800 + 2.412\, x_1 + 2.362\, x_2 + 0.787\, x_3 + 2.688\, x_4 - 1.126\, x_1^2 - 1.126\, x_2^2 - 0.751\, x_3^2 - 1.376\, x_4^2 + 1.006\, x_1 x_3 + 1.281\, x_1 x_4 - 0.969\, x_2 x_3 + 0.544\, x_3 x_4 \tag{11}$$

Production of porcelain insulator using the optimal formulations obtained from the optimality test (Fig. 1) was done. Inspection of the desirability plot (Fig. 1) indicates that the established empirical models [20] were able to predict factor settings required to obtain the responses at composite desirability of 93.6 % with individual desirabilities of each response as 99 %, 97 %, 99 % and 80 % for compressive strength, modulus of rupture, linear shrinkage and apparent porosity respectively. The values of individual desirability and the composite desirability respectively approximate to 1 which signifies that the optimization result is highly desirable. Therefore, it is seen that the insulators produced from Ohiya clay performed optimally at the factor settings of 0.4242, 2.0, 0.4646 and -0.3384 for quantity of clay, feldspar, temperature and silica respectively. The optimal mixing ratio for clay, feldspar and silica in wt % is 42:32:20 at a firing temperature of 1250 ^{o}C as shown in the desirability plot.

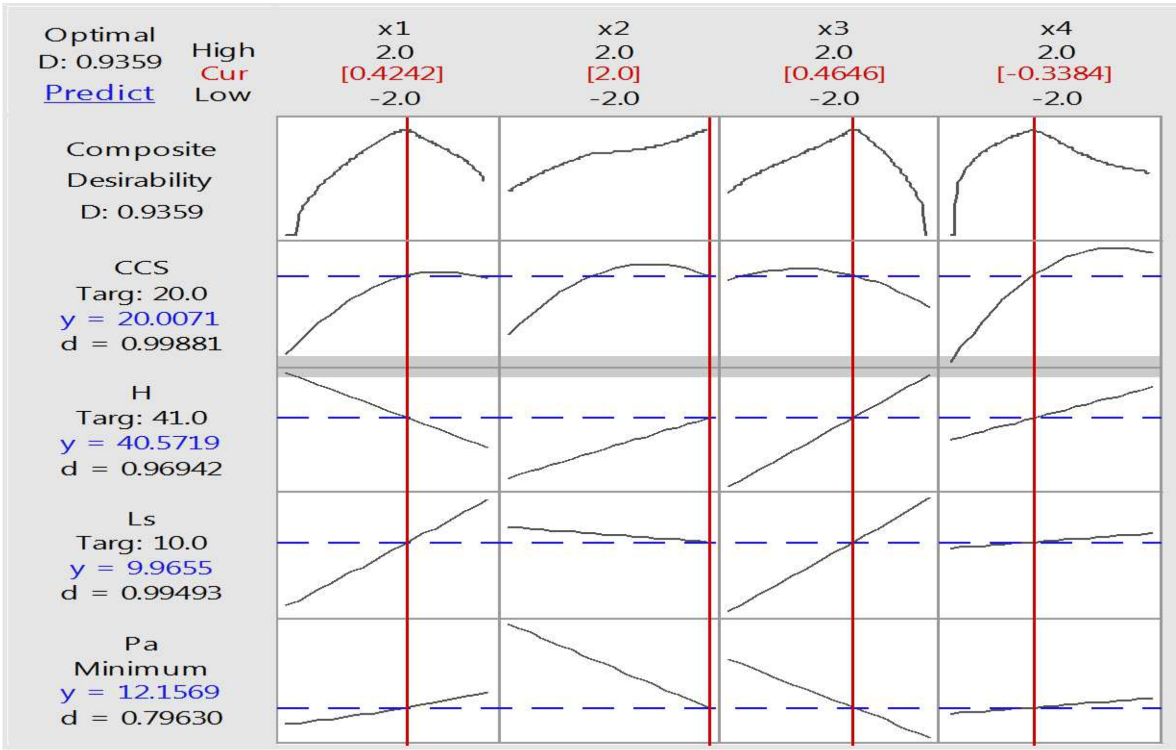

Fig. 1: Optimization plot of the insulator parameters

The optimal mixing ratio for Ohiya clay, feldspar and silica as predicted above was used in the clayey body formulations for low and high voltage insulators shown in Fig. 2.

Fig. 2: High and low Voltage Insulators

Experimental validation of the performance of the porcelain insulator shown in Fig. 3, 4 and 5 respectively indicates that the porcelain insulator had a maximum breakdown voltage of 26 kV/mm when fired at 1300 ºC (Fig. 3), insulation resistance of 6.96 GΩ when injected 5000 volts (Fig. 4) and a polarization index of 1.46 (Fig. 5). The electrical porcelain sample produced have a maximum breakdown voltage of 26 kV/mm when fired at 1300 ºC, however from the plot in Fig. 3, the optimal temperature was obtained as 1250 ºC and the breakdown voltage (dielectric strength) at this temperature is 17 kV/mm.

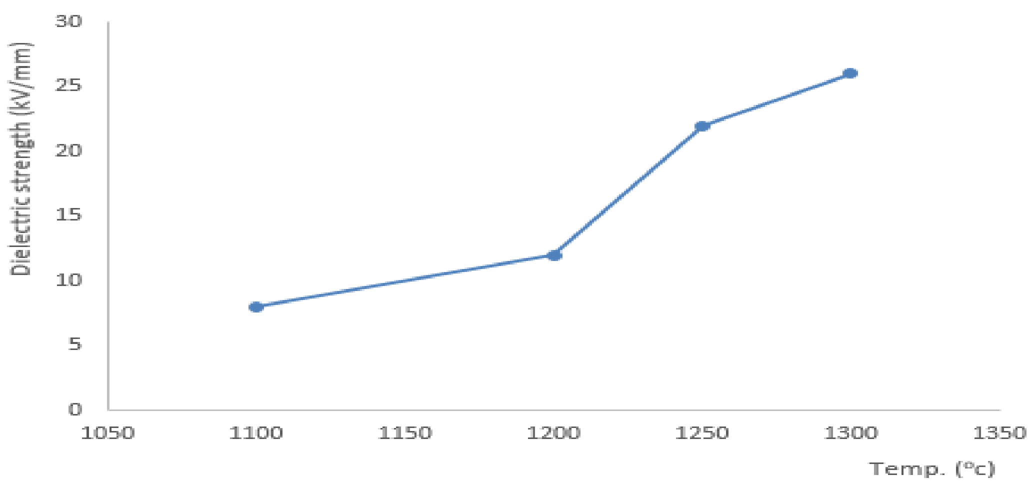

Fig. 3: Dielectric Strength Test of the Porcelain Insulators

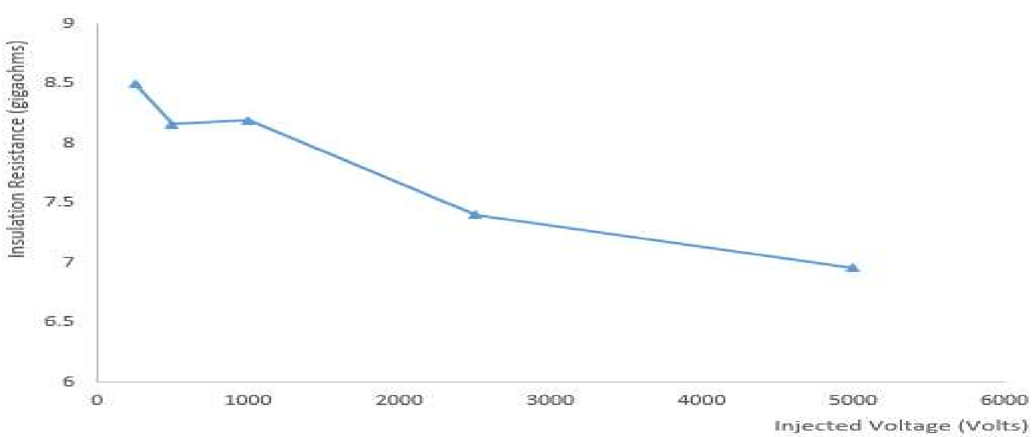

Fig. 4: Insulation Resistance Test of the Porcelain Insulators

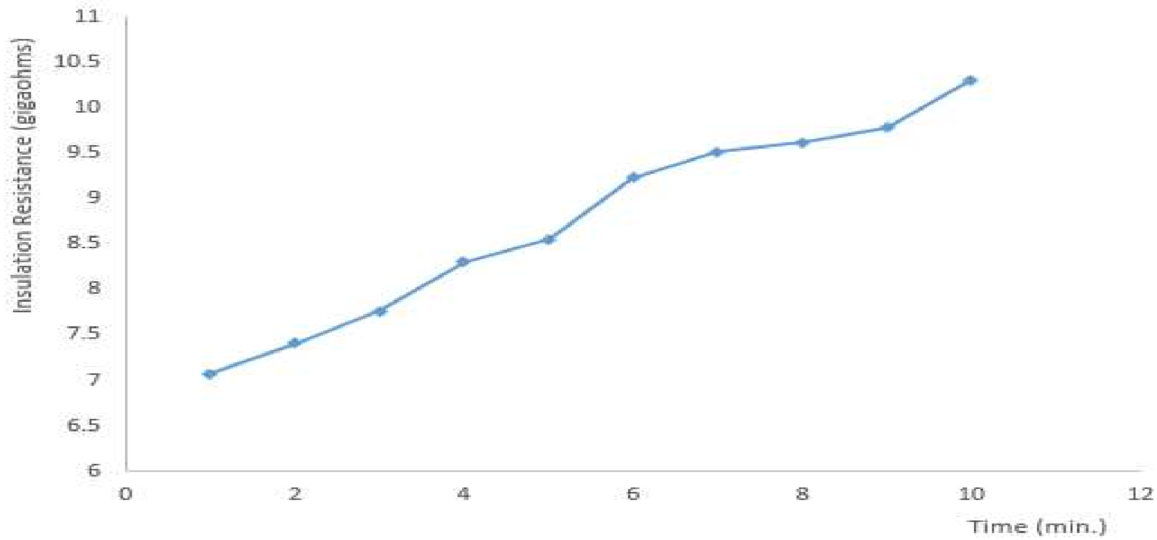

Fig. 5: Polarization Index Test

Corroborating this result, [21] reported that porcelain insulators produced at temperatures exceeding 1300 °C experienced a drastic reduction in their dielectric strength. Hence, Ohiya clay deposits together with its additives offered good prospects for their exploitation in the production of high voltage and low voltage electric porcelain insulators using the optimal mix ratio, since the values of the breakdown voltage satisfies the required standards as recommended by [22,17,23]. Table 4 shows the experimental validation of electrical insulator from Ohiya clay formulated at optimal mix ratio.

Table 4: Experimental Validation/Comparative analysis of Porcelain electrical insulator from Ohiya Clay

S/N	Responses	Level Predicted	Actual	% Error	NIS/ISO Specifications
1	Modulus of Rupture (kg/cm^2)	40.00	41.00	1.05	≥20 kg/cm^2
2	Apparent Porosity (%)	12.20	12.72	4.30	≤15 %
3	Compressive Strength (MPa)	20.00	21.00	4.70	≥10 MPa
4	Linear Shrinkage (%)	9.96	10.10	0.40	7-12 %
5	Insulation Resistance (GΩ)	-	6.96	-	≥5 GΩ

	Dielectric Strength (kV/mm)				
6	(Low Voltage)	-	17.00	-	10-20 kV/mm
	Dielectric Strength (kV/mm)				
7	(High Voltage)	-	26.00	-	21-30 kV/mm
8	Polarization Index	-	1.46	-	-

Furthermore, inspection of the desirability plot for **t**iles produced from Ohiya Clay (Fig. 6) indicates that the established empirical models [20] were able to predict factor settings required to obtain the responses at composite desirability of 96% with individual desirability of each response as 99 %, 100 %, 87 % and 100 % for modulus of rupture, linear shrinkage, water absorption rate and apparent porosity respectively.

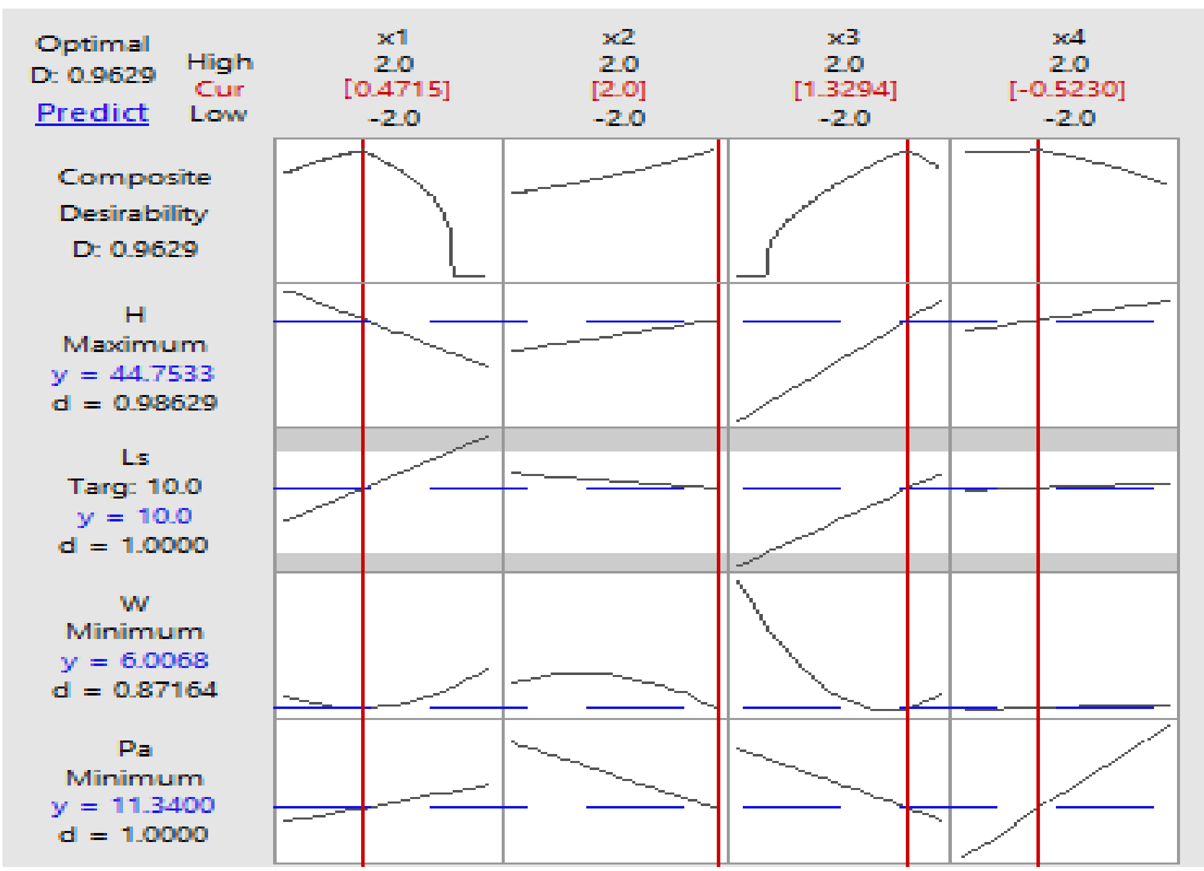

Fig. 6: Optimization plot of the tile parameters.

The values of individual desirability and the composite desirability respectively approximate to 1 which signifies that the optimization result is highly desirable. Therefore, it is seen that the tile produced from Ohiya clay performed optimally at the factor settings of 0.47, 2.0, 1.33 and -0.52 for quantity of clay, feldspar, temperature and silica respectively. The optimal mixing ratio for clay, feldspar and silica in wt % is 42:33:17 at a firing temperature of 1300 ºC as shown in the desirability plot. The optimal mixing ratio for Ohiya clay, feldspar and silica as predicted above and the addition of diatomite and talc (7 wt. %) was used in the clayey body formulations for tiles shown in Fig. 7. The experimental validation of tile sample carried out using tile specimens formulated at the optimal mix ratio is shown in table 5. The percentage error for all the responses studied is within ± 5 %, hence the optimality test is validated.

Table 5: Experimental Validation/Comparative analysis of Tiles from Ohiya Clay

S/N	Responses	Level Predicted	Actual	% Error	NIS/ISO Specifications
1	Modulus of Rupture (kg/cm^2)	44.75	45.33	1.20	≥12 kg/cm^2
2	Linear Shrinkage (%)	10.0	9.93	0.70	7-10 %
3	Water Absorption rate (%)	6.0	5.73	4.70	1-10 %
4	Apparent Porosity (%)	11.34	11.70	3.10	1-15 %

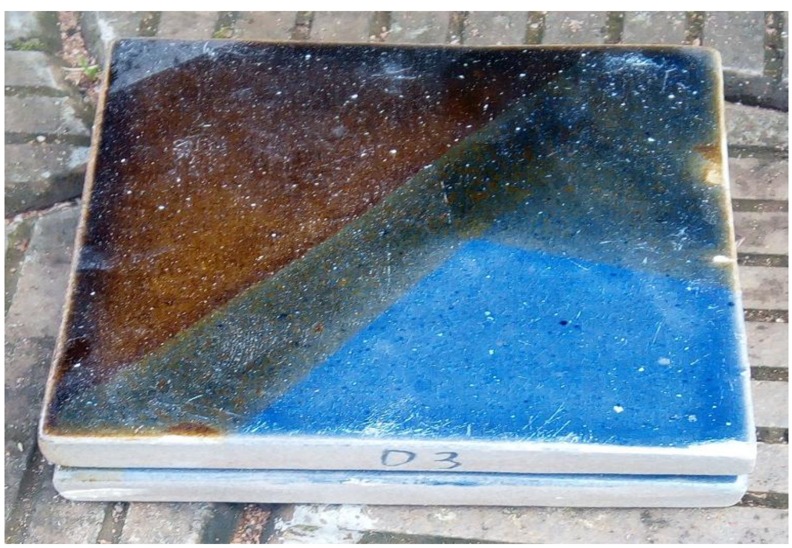

Fig.7: Tiles from Ohiya Clay

As shown in table 6, the tile produced can be used as porcelain tile, wall tile, floor tile and exterior tiles since it meets the required properties in terms of modulus of rupture, water absorption rate, porosity and linear shrinkage.

Table 6: Ohiya clay tile Applications

S/N	Tile Applications	NIS/ISO Specifications	Remarks
1.	**Porcelain**	a. Low Porosity (≤12 %) b. High modulus of rupture(≥30 kg/cm^2) c. Water absorption rate (≤10 %)	Suitable
2.	**Interior**		
	a. Wall tile	a. MOR ≥12 kg/cm^2 b. Water absorption rate (≤10 %)	Suitable
	b. Floor tile	a. MOR ≥30 kg/cm^2 b. Low porosity	Suitable
3.	**Exterior tile**	a. MOR ≥40 kg/cm^2 b. Low absorption rate	Suitable

It is also observed that the optimum temperature had a beneficial effect on the development of certain technological properties such as its contribution to the increased mechanical strength since decreasing porosity also reduced crack formation. This formulation gave high variety of tile application as against the formulation of [24] that obtained responses suitable for floor tile only.

In addition, the tableware performance parameters optimized using the desirability plot (Fig. 8) indicates that the established empirical models [20] were able to predict factor settings required to obtain the responses at composite desirability of 93% with individual desirability of each response as 99 %, 83 %, 91 % 90 % and 99 % for compressive strength, modulus of rupture, linear shrinkage, water absorption rate and apparent density respectively.

The values of individual desirability and the composite desirability respectively approximate to 1 which signifies that the optimization result is highly desirable. Therefore, it is seen that the tableware produced from Ohiya clay performed optimally at the factor settings of 0.46, 2.0, -0.91 and 0.15 for quantity of clay, feldspar, temperature and silica respectively.

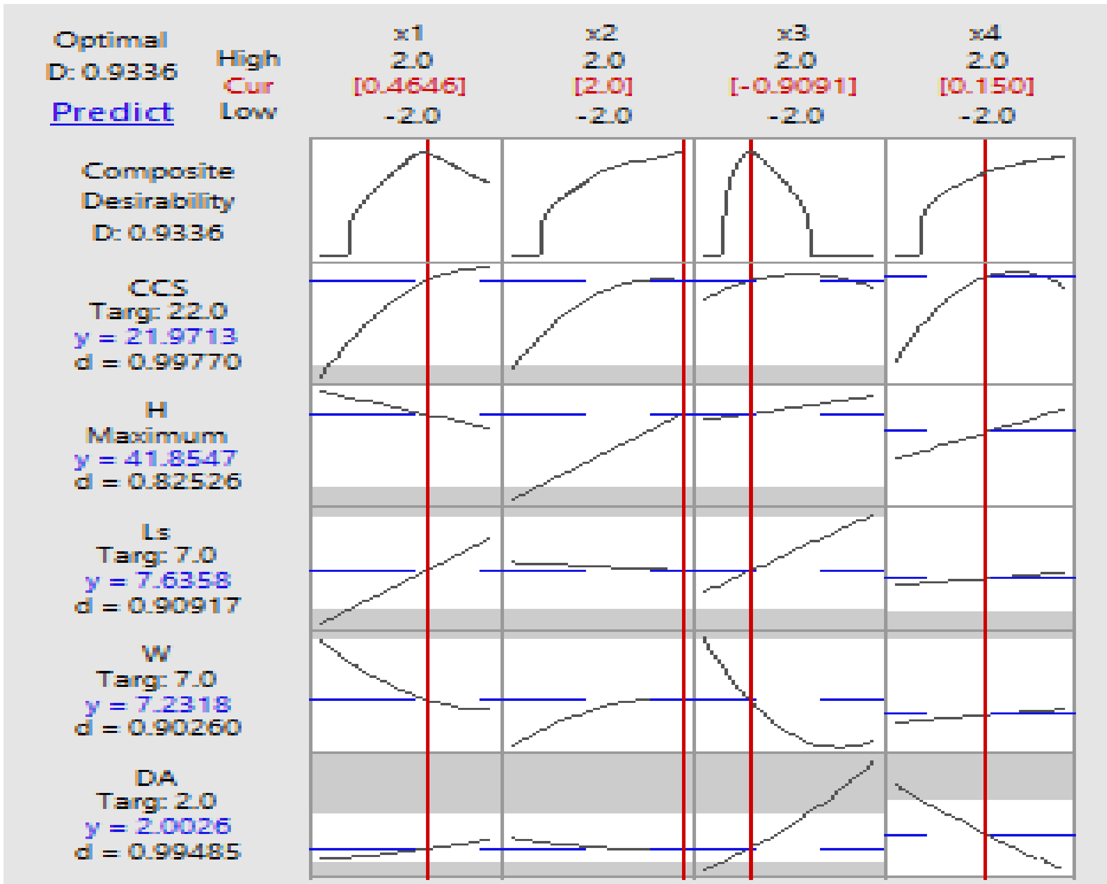

Fig. 8: Optimization plot of the tableware parameters.

In natural units the optimal mixing ratio for clay, feldspar and silica in wt % is 41:32:27 at a firing temperature of 1000 ^{o}C as shown in the desirability plot. The optimal mix ratio was used in the clayey body formulations for dishes fired at 1000 ^{o}C as shown in Fig. 9.

Fig. 9: Serving dishes from Ohiya Clay

The experimental validation of tableware sample carried out using tableware specimens formulated at the optimal mix ratio is shown in table 7.

Table 7: Experimental Validation/Comparative analysis of Tableware (serving dish) from Ohiya Clay

S/N	Responses	Level Predicted	Actual	% Error	NIS/ISO Specifications
1	Modulus of Rupture (kg/cm^2)	41.85	42.01	0.35	≥21 kg/cm^2
2	Apparent density (g/cm^3)	2.00	2.05	2.40	2.0-2.5 g/cm^2
3	Compressive Strength (mPa)	21.97	21.7	1.24	≥15 mPa
4	Linear Shrinkage (%)	7.64	7.50	1.80	≤10 %
5	Water absorption rate (%)	7.23	7.20	0.41	≤10 %

The costs incurred in the production of the ceramic products from Ohiya clay is shown in Table 7. From the cost analysis presented in Table 8, the sum required to produce 11 kV electric insulator, 400×400 mm tile and serving dish are respectively six hundred and twenty-five naira (₦625), three hundred and twenty-two naira (₦322) and three hundred and four seven (₦347) only. However, the market price of 11 kV electric pot insulator, 400×400 mm tile and serving dish are respectively one thousand naira (₦1000), three hundred and fifty naira (₦350) and four hundred and twenty naira (₦420) only.

Table 8: Cost Analysis of Optimal Ceramic Products from Ohiya Clay

			Electrical Insulator		Tiles		Tableware (Serving Dish)	
S/N	Description	Unit Price (₦/Kg)	Quantity (Kg)	Amount (₦)	Quantity (Kg)	Amount (₦)	Quantity (Kg)	Amount (₦)
1	Ohiya Clay	15	1.26	15	0.76	11	1.07	16
2	Feldspar	100	0.96	96	0.59	59	0.83	83
3	Silica	100	0.6	60	0.3	30	0.7	70
4	Pyrophylite	300	0.18	54	-	-	0.16	48
5	Sawdust	50	-	-	-	-	-	-
6	Talc	300	-	-	0.14	42	-	-
7	Labour Cost	-	-	300	-	80	-	80
8	Miscellaneous	-	-	100	-	100	-	50
	Total			**625**		**322**		**347**

Hence, the production of electrical insulator, tiles and tableware at the optimal settings can save about three hundred and seventy five naira (₦375), twenty eight naira (₦28) and seventy three naira (₦73) respectively which translates to 16 %, 60 %, 9 %, 21 % and 69 % in profit for these products.

4 Conclusion

This study involves the formulation of Ohiya clay-feldspar-silica mix into quality ceramic porcelain products in accordance with end users desires. This is expected among other things to attract investors to harness the stranded clayey natural resource in Abia State for the overall economic growth of Nigeria. Optimal product design for producing standard porcelain products from this clay were determined using desirability function analysis. The results revealed that the alumino-silicate constitutes 91% of the total mineralogical composition of Ohiya clay and 42:32:20 at a firing temperature of 1250/1300 ^{o}C; 42:33:17 at a firing temperature of 1300 ^{o}C; 41:32:27 at a firing temperature of 1000 ^{o}C as the optimal mix of the clay, feldspar and silica for producing standard low/high voltage insulators, tiles and tablewares respectively. The production of the 11 kV electric insulator, 400×400 mm tile, serving dish at optimal settings translates to 60

%, 9 % and 21 % in profit for these products. Hence, adoption of the optimal mixing ratio as well as exploitation of this natural resource is highly recommended.

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Figures

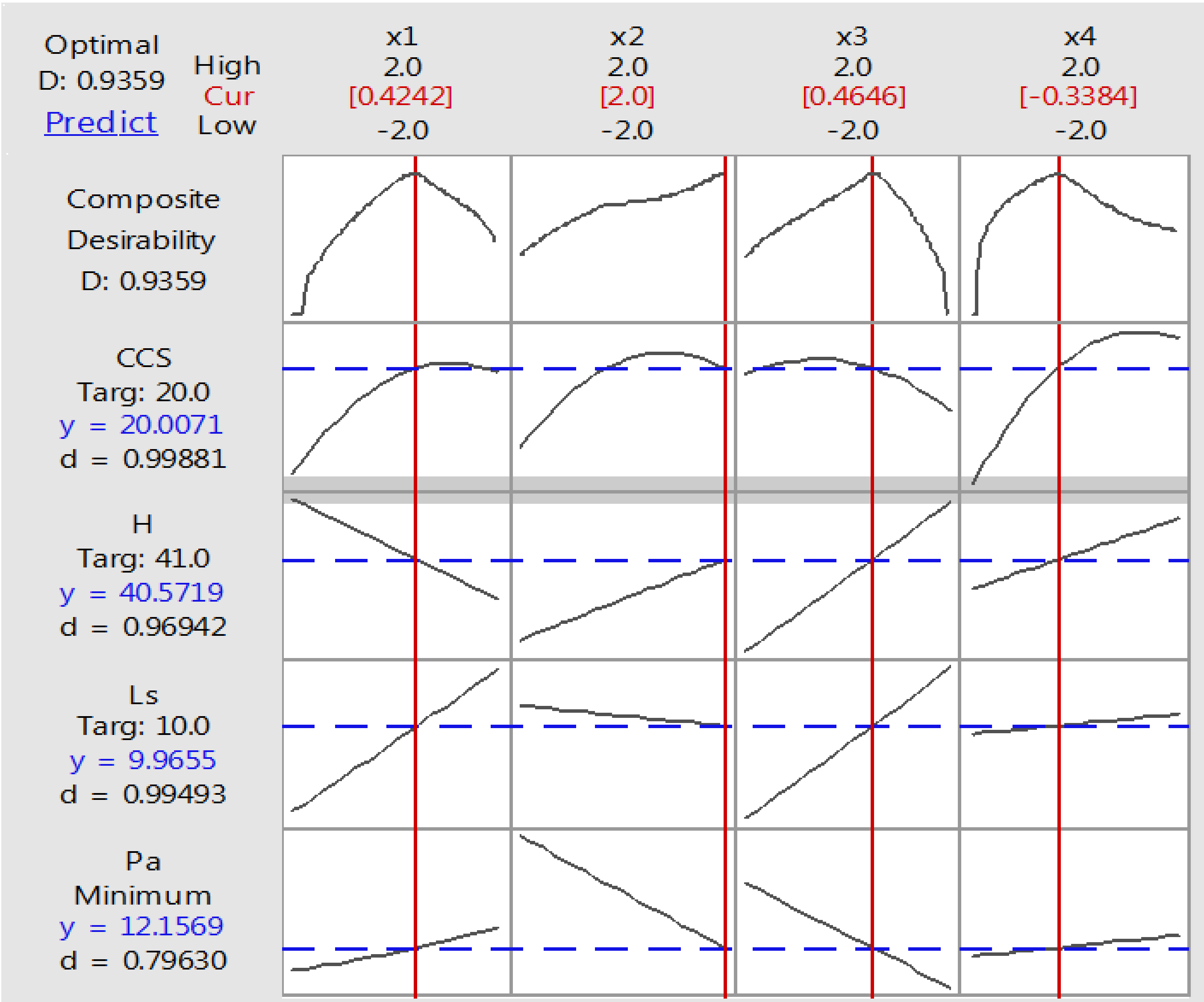
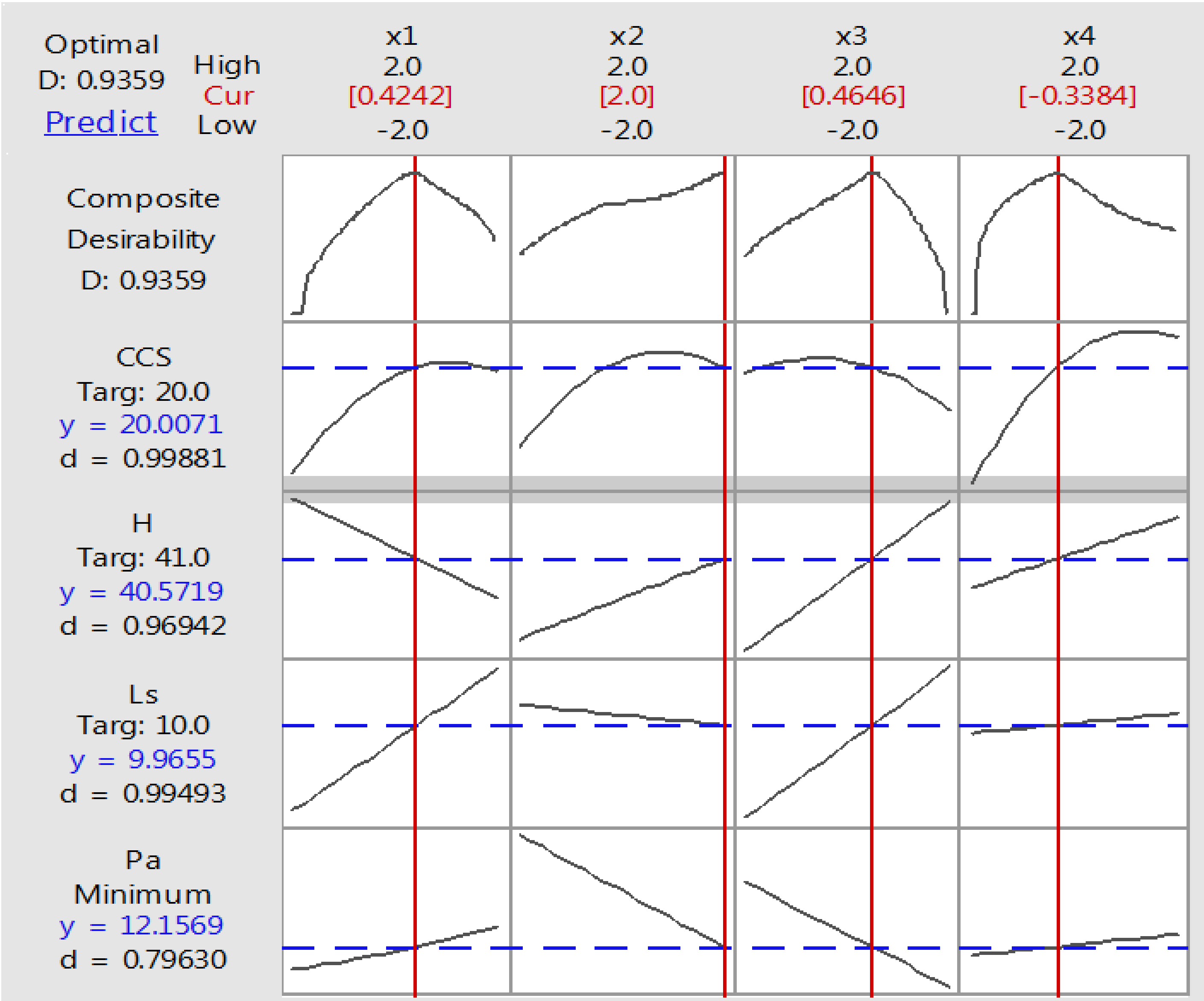


Figure 1

Optimization plot of the insulator parameters



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Optimization plot of the insulator parameters

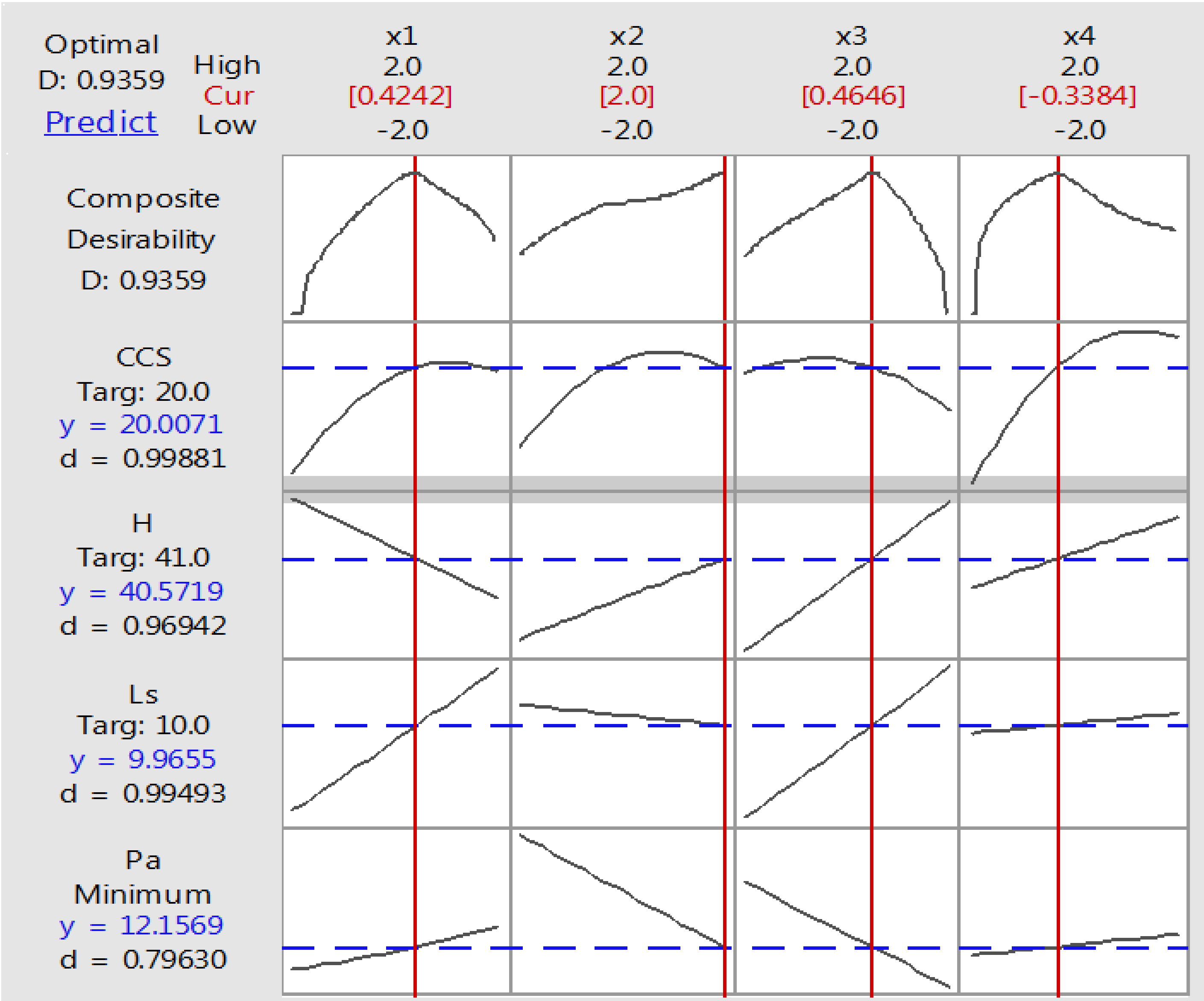


Figure 1

Optimization plot of the insulator parameters

Figure 2

High and low Voltage Insulators

Figure 2

High and low Voltage Insulators

Figure 2

High and low Voltage Insulators

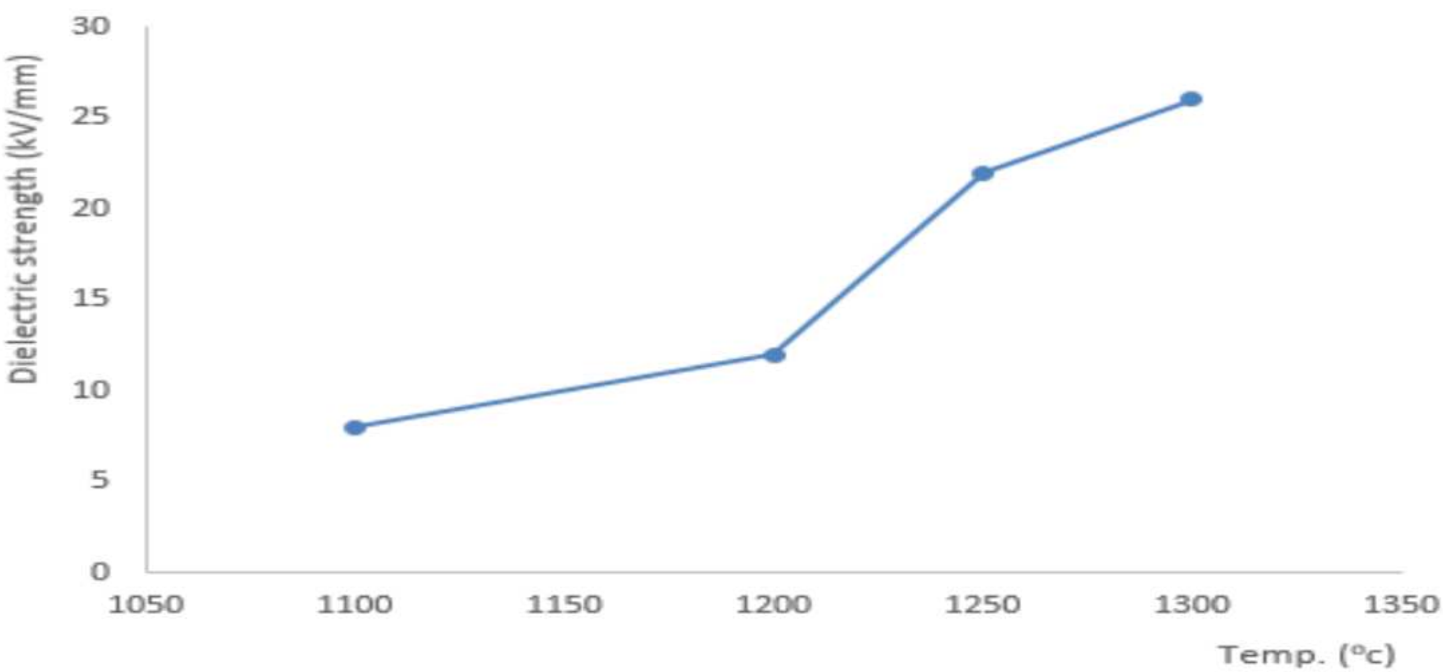
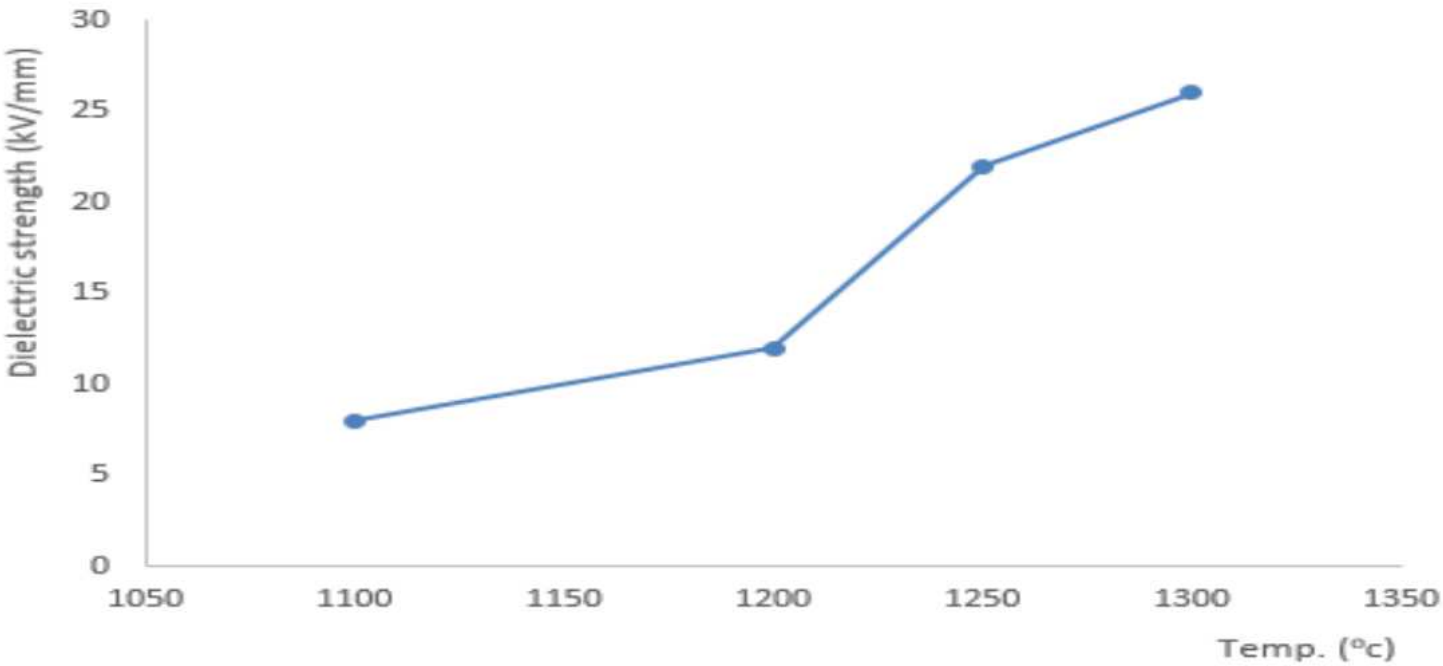


Figure 3

Dielectric Strength Test of the Porcelain Insulators



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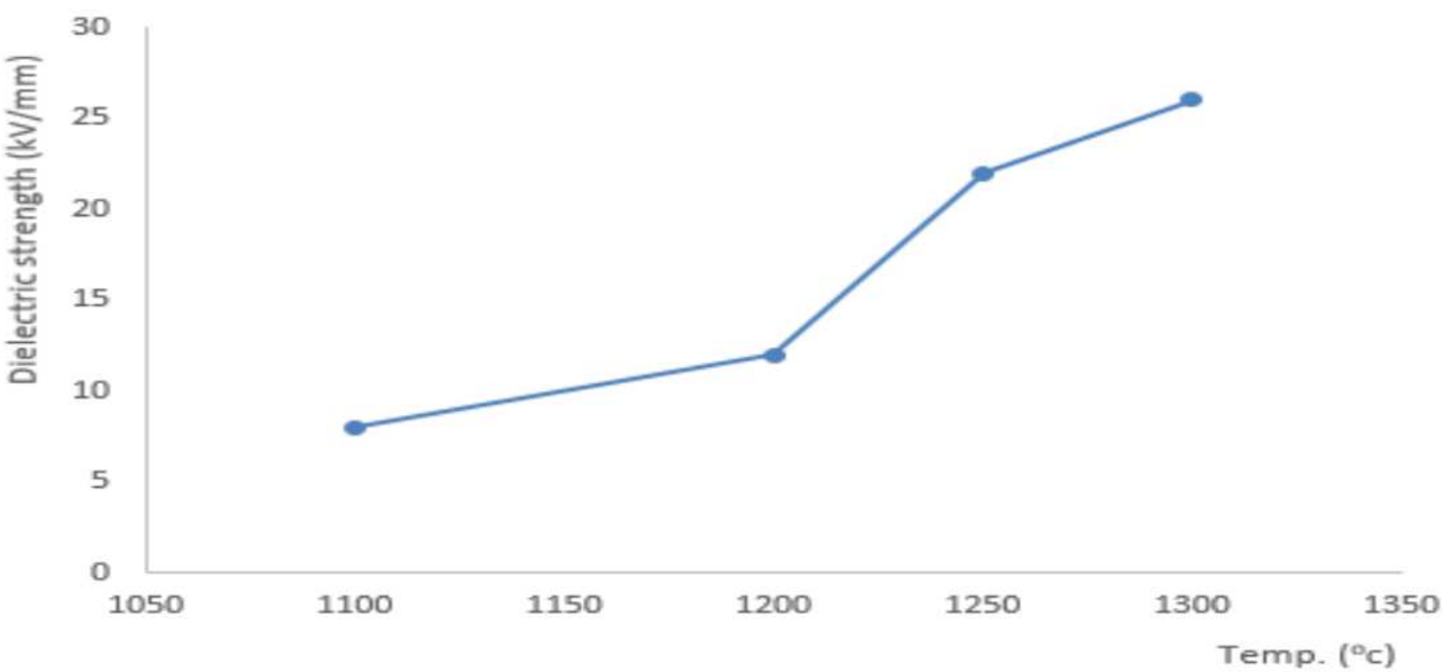


Dielectric strength (kV/mm)
30
25
20
15
10
5
0
1050
1100
1150
1200
1250
1300
1350
Temp. (°c)

Figure 3

Dielectric Strength Test of the Porcelain Insulators

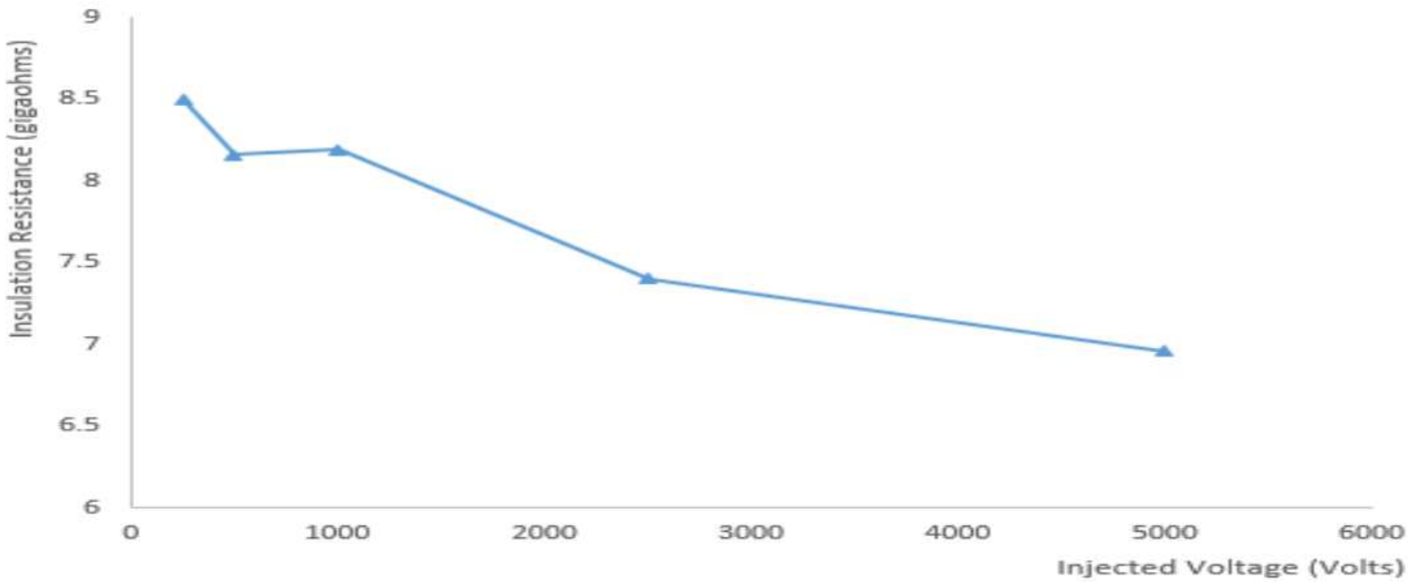


Figure 4

Insulation Resistance Test of the Porcelain Insulators

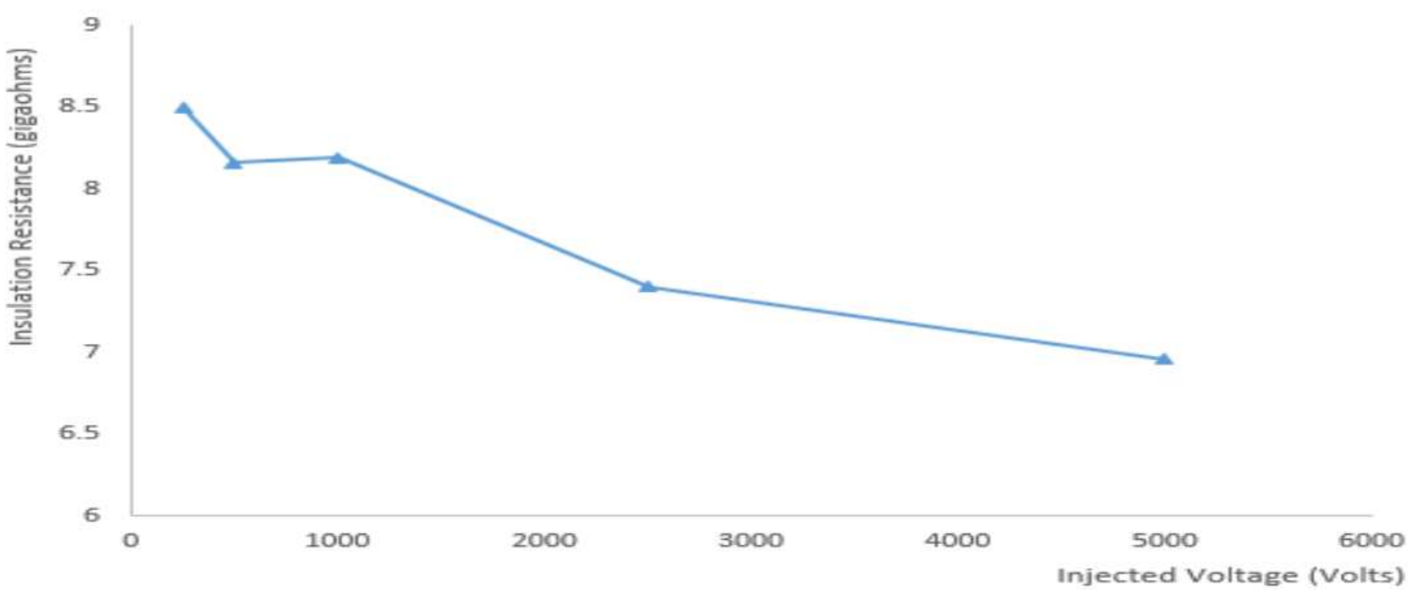
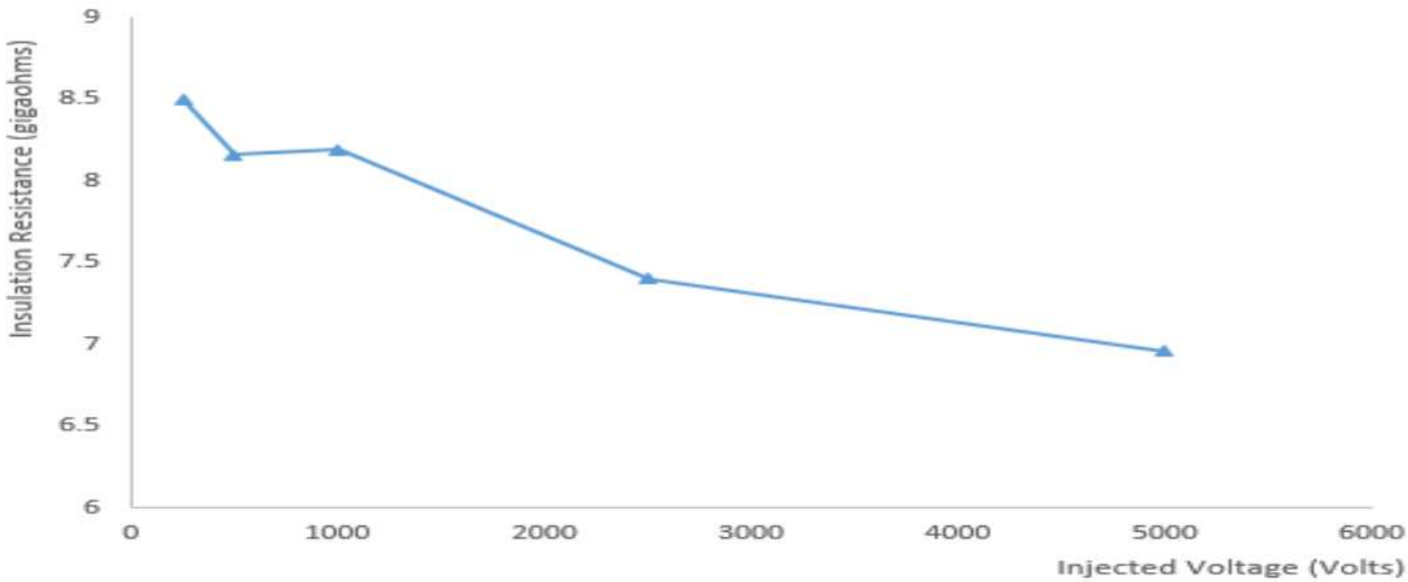

Insulation Resistance (gigaohms)
9
8.5
8
7.5
7
6.5
6
0
1000
2000
3000
4000
5000
6000
Injected Voltage (Volts)

Figure 4

Insulation Resistance Test of the Porcelain Insulators



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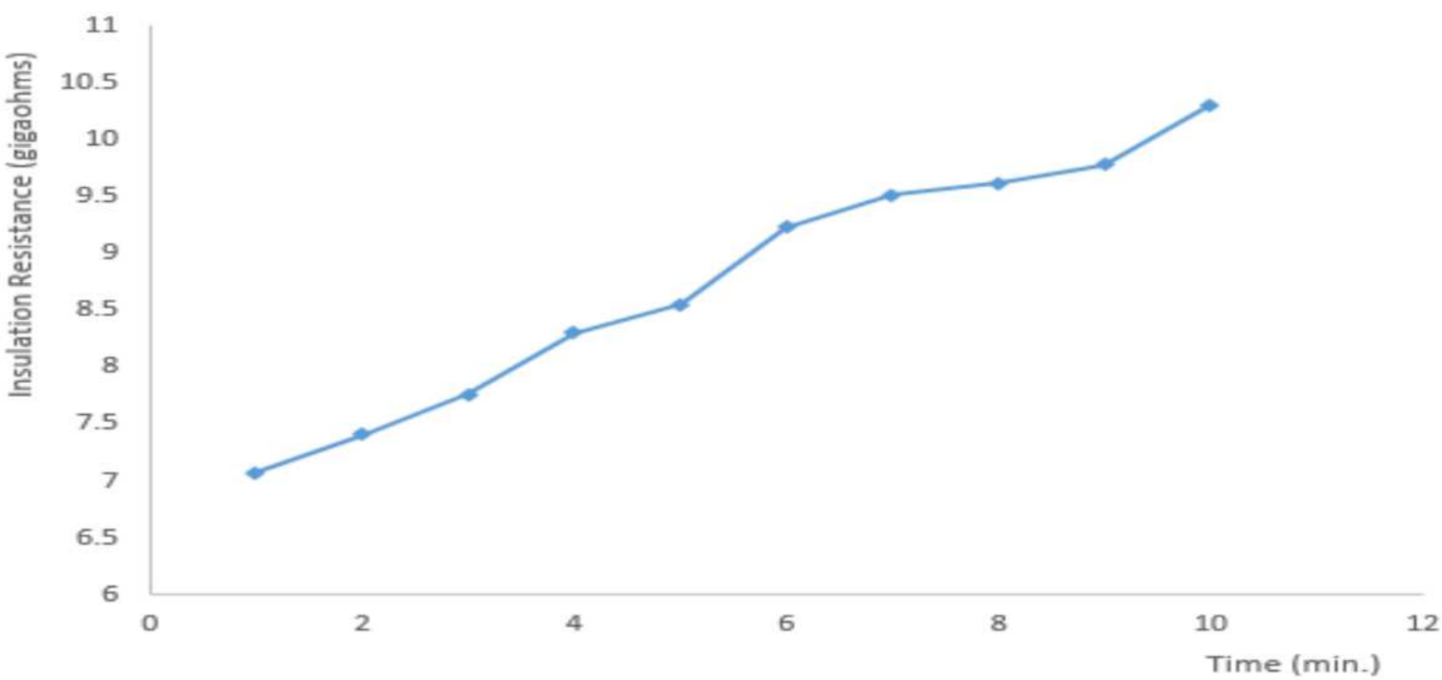


Figure 5

Polarization Index Test

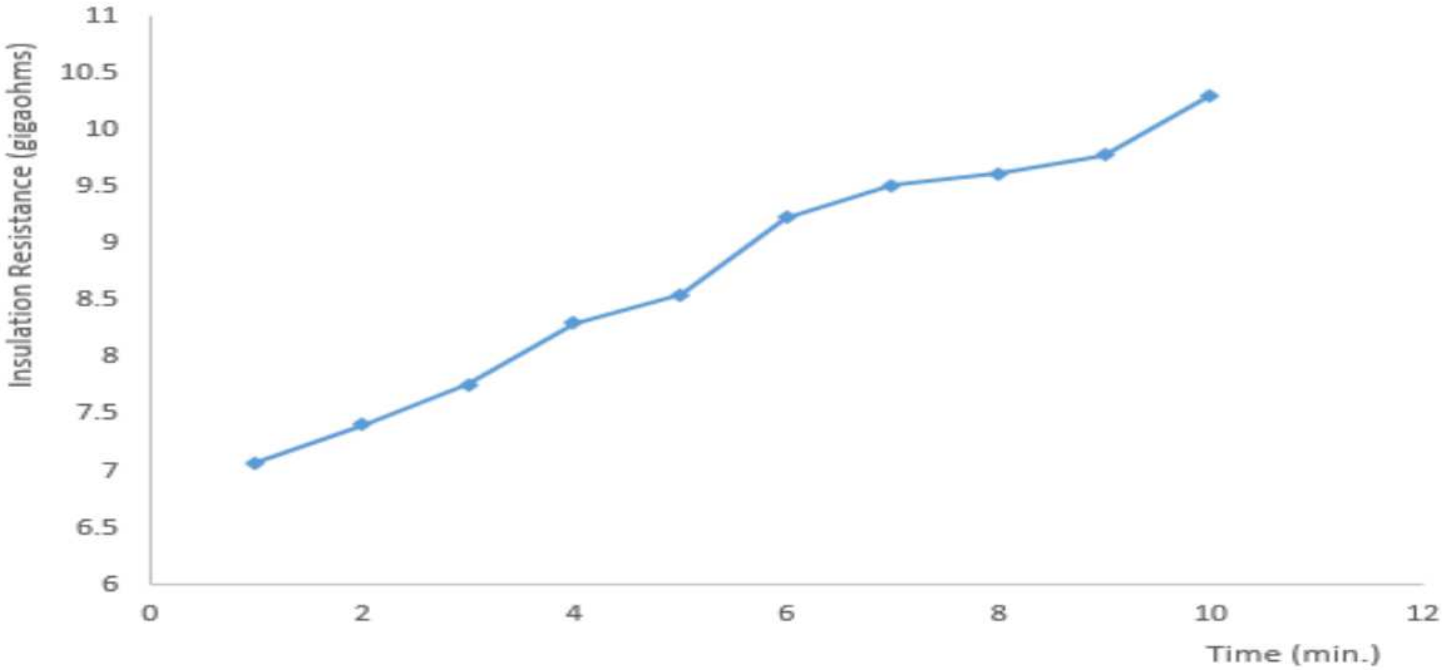


Figure 5

Polarization Index Test

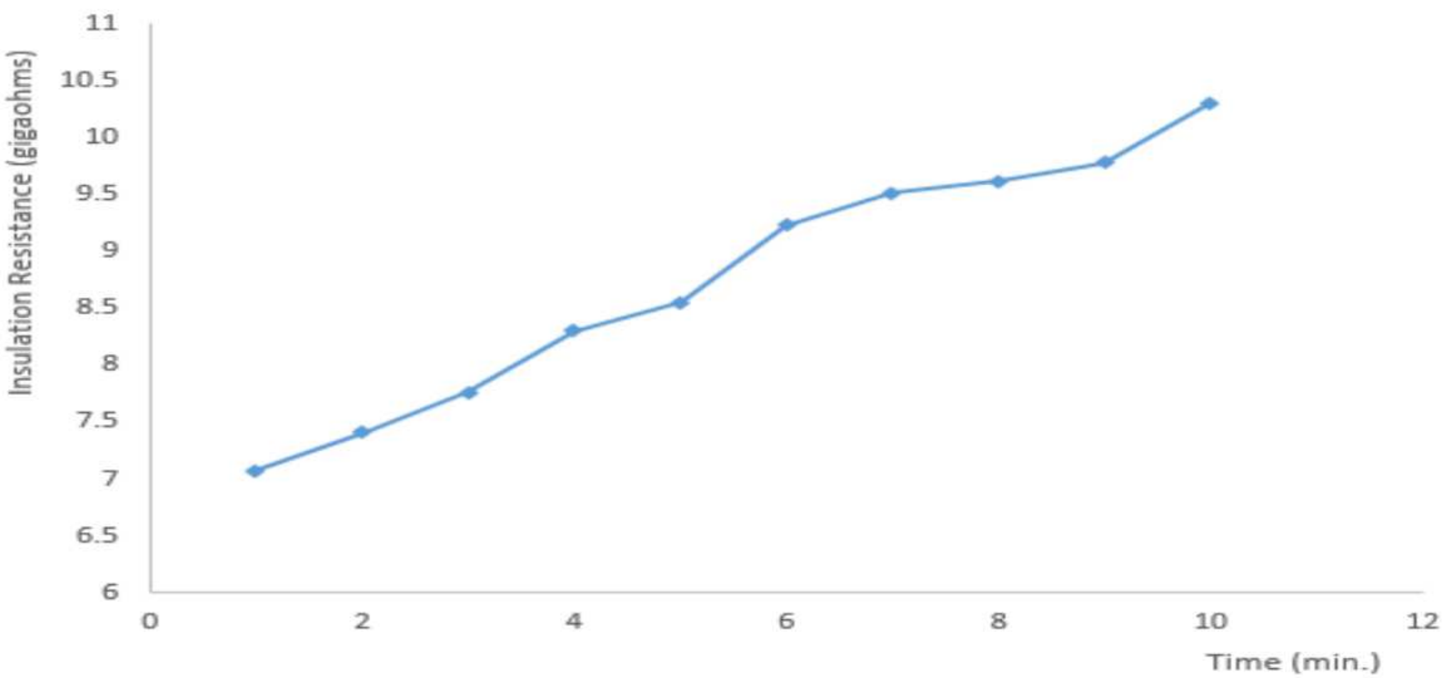


Figure 5

Polarization Index Test

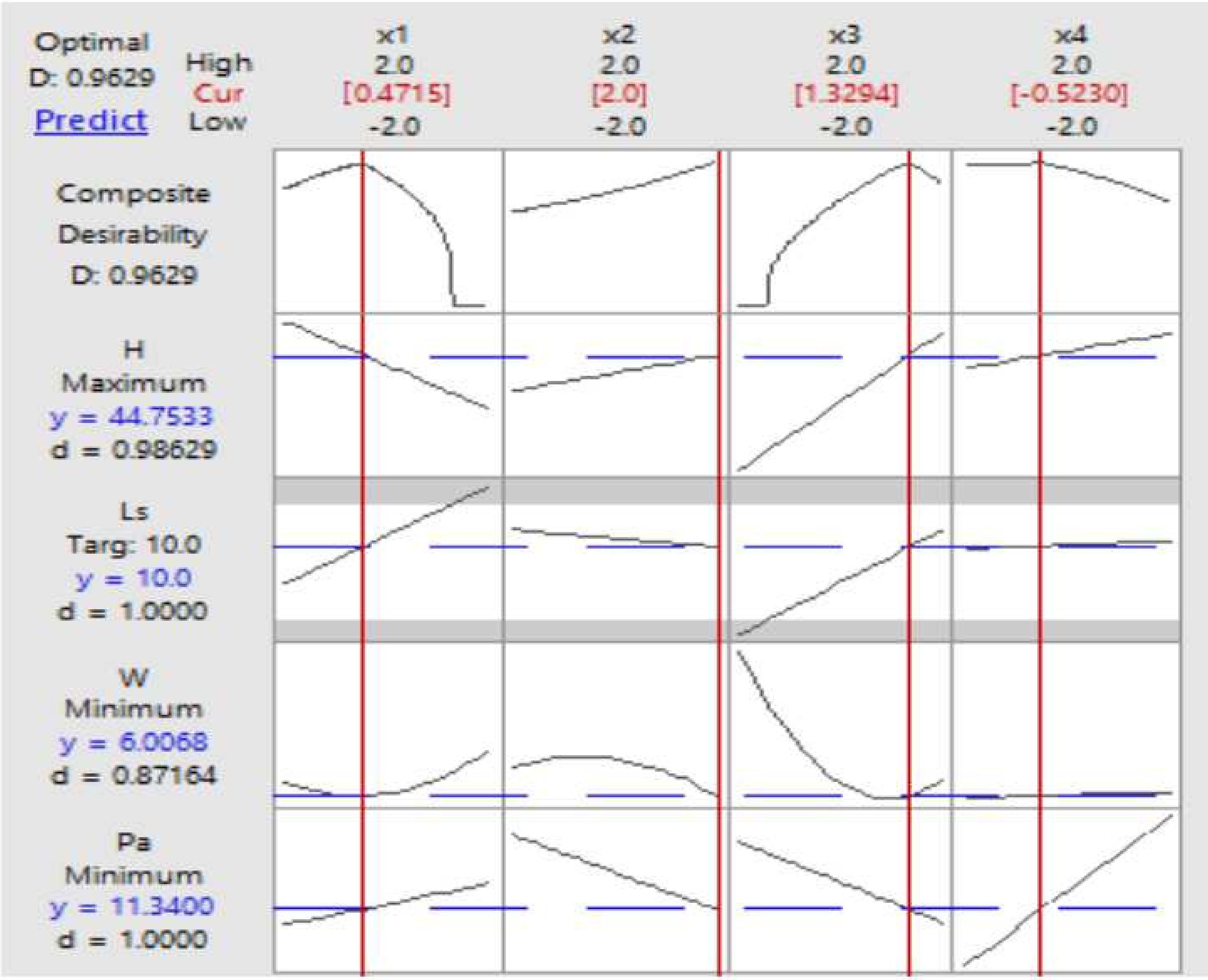
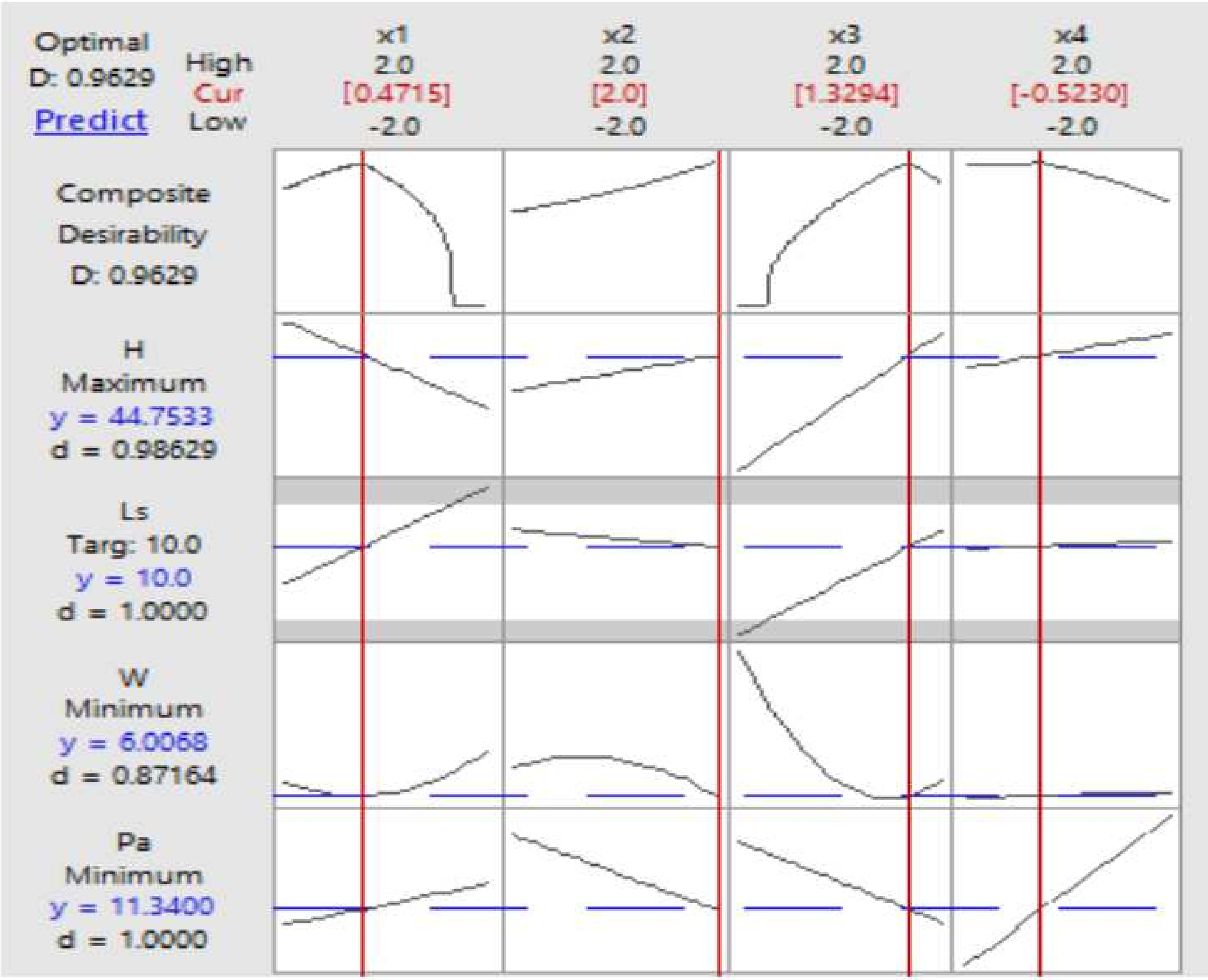


Figure 6

Optimization plot of the tile parameters



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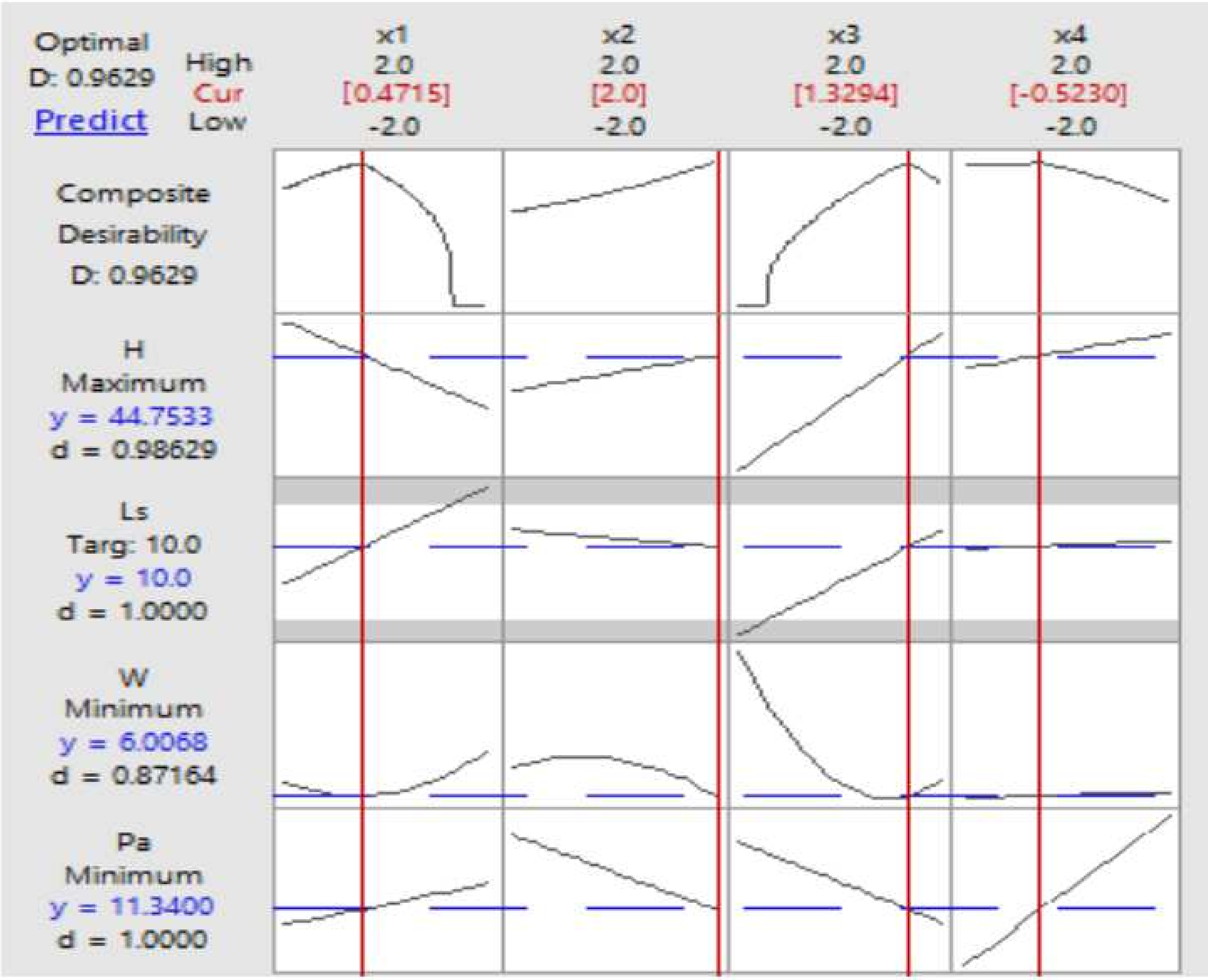

Figure 6

Optimization plot of the tile parameters

Figure 7

Tiles from Ohiya Clay

Figure 7

Tiles from Ohiya Clay

Figure 7

Tiles from Ohiya Clay

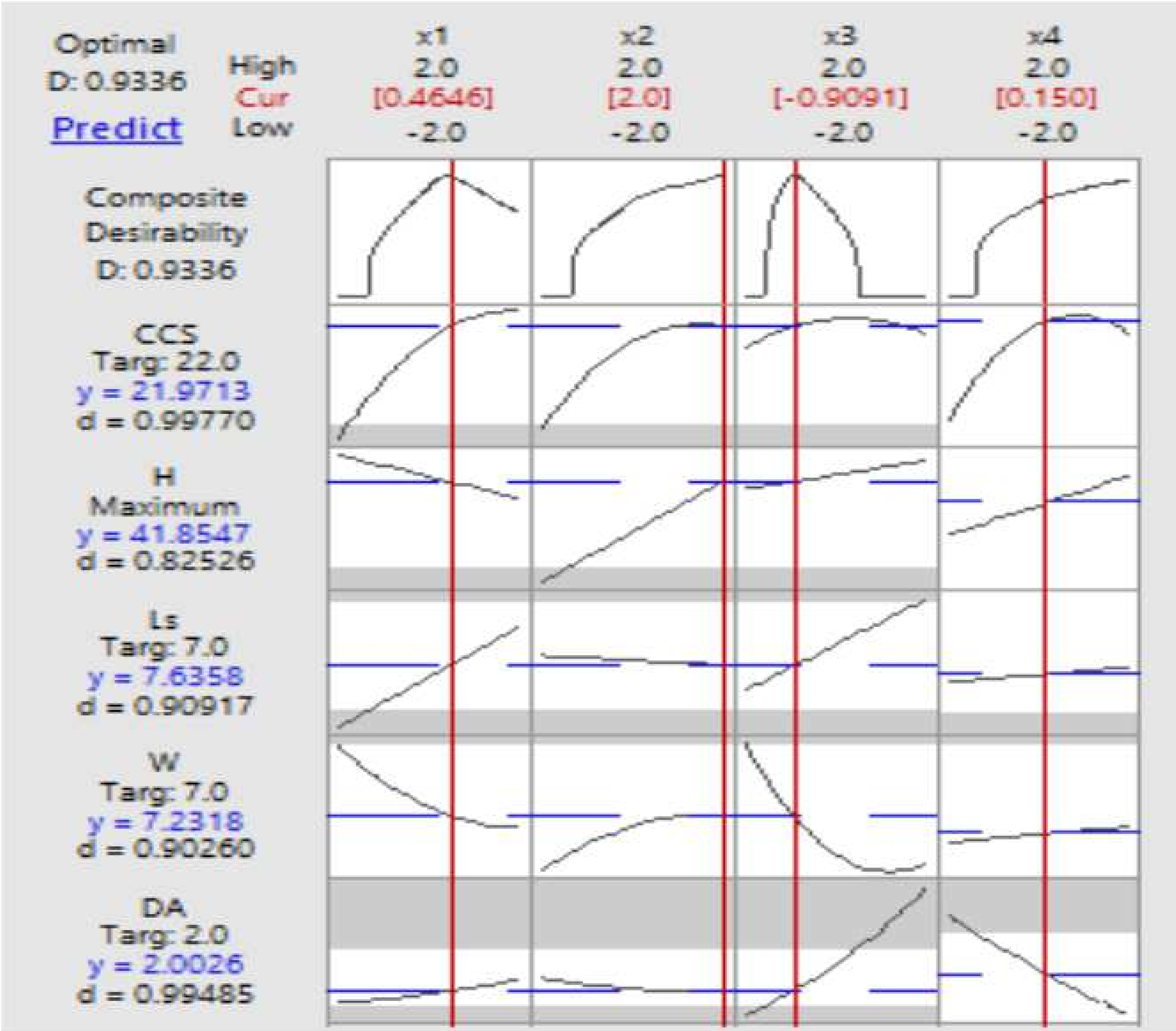

Figure 8

Optimization plot of the tableware parameters

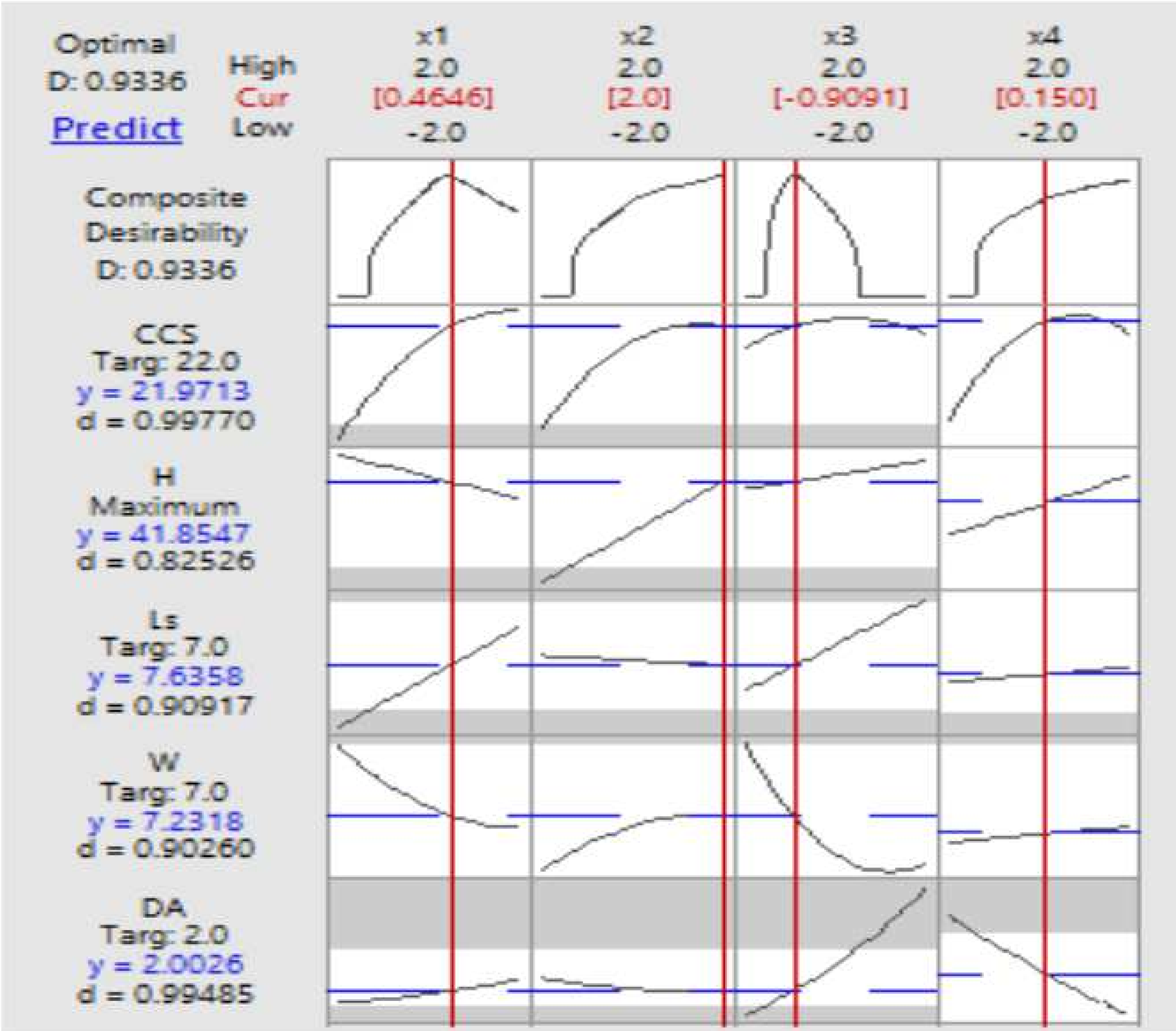

Figure 8

Optimization plot of the tableware parameters

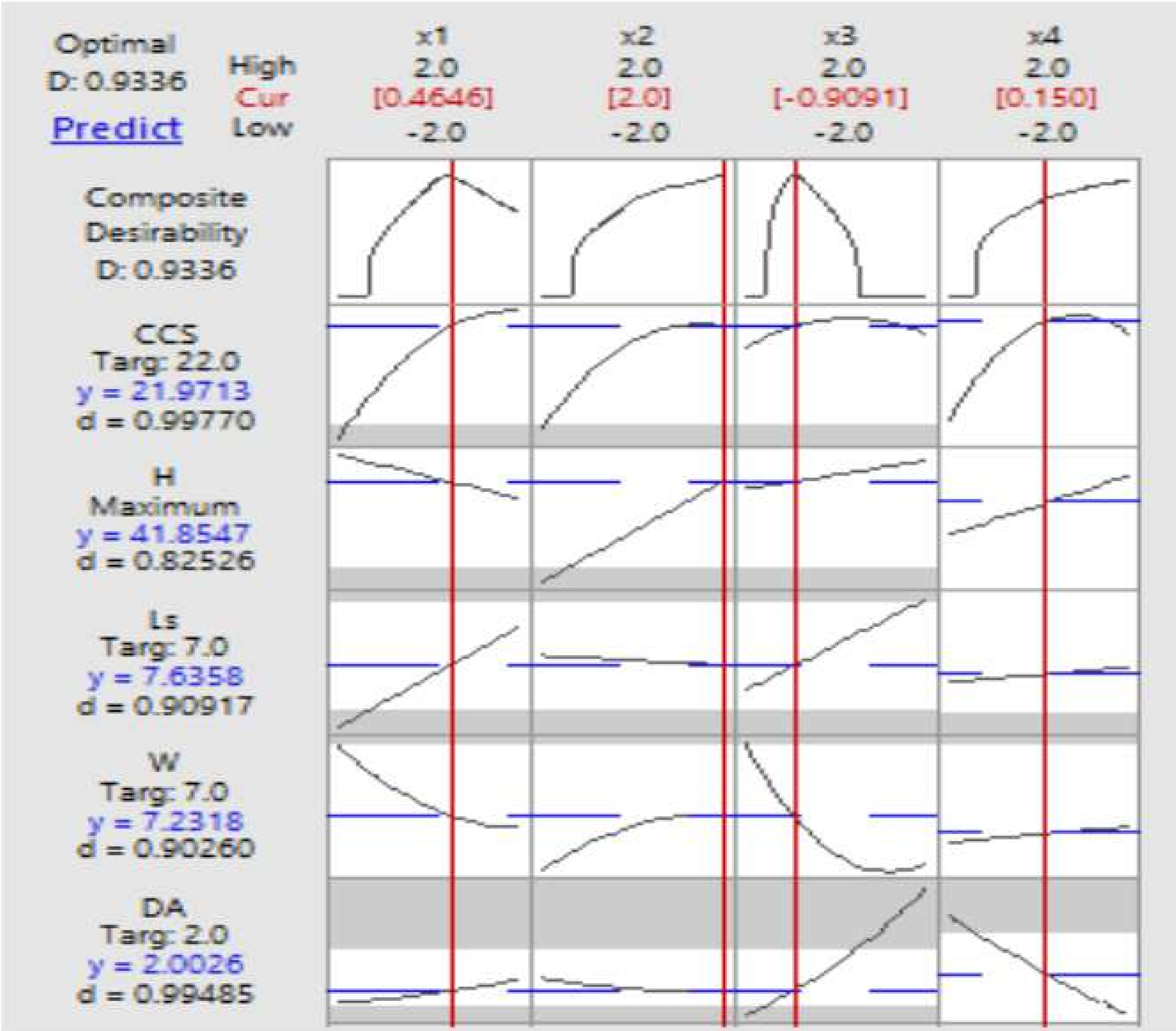

Figure 8

Optimization plot of the tableware parameters

Figure 9

Serving dishes from Ohiya Clay

Figure 9

Serving dishes from Ohiya Clay

Figure 9

Serving dishes from Ohiya Clay