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Effects of glass powder and Gypsum (Timchemt) on the thermal and mechanical properties of plaster bricks

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ABSTRACT

The present research aims to study the effect of glass powder extracted from the glass waste disposal area in Ouargla (southern Algeria) on the thermomechanical properties of plaster bricks. Therefore, density, compressive strength, flexural strength, thermal conductivity, and thermal resistance were measured in the laboratory using mixtures generated through the response surface methodology (RSM). This RSM technique was used to assess the influence of gypsum (95% - 100%) and glass powder (0% - 5%) on the behavior of hardened plaster bricks. The experimental results and RSM evaluation show a significant increase in compressive and flexural strength at the maximum and minimum levels of Timchemt and glass powder, and detailed scanning electron microscopy (SEM) analyses supported the results. Consequently, quadratic mathematical models were developed using the RSM method applied to the obtained results. Analysis of variance (ANOVA) yielded a (P-value <0.05) and correlations exceeding 91% for all the studied parameters. Probability plots showed excellent correlation between predicted and experimental values, and the 2D and 3D contours of the RSM demonstrated that the fitted models work very well and can provide the appropriate relationship between the selected parameters and thermomechanical properties.

Keywords: Thermal and mechanical, Gypsum (Timchemt), glass powder, plaster bricks, Response Surface Methodology.

INTRODUCTION

Algeria with its vast surface area encompasses a heterogeneity of local materials that deserve to be valorized, for example those located in the southern region of the country, namely: sand dunes, clays, tuff, gypsum and others that are still poorly valorized. Most of the building materials currently used in the Saharan regions are poorly adapted in terms of climatic and environmental conditions, sustainability and economics.

Recently, the construction sector has increasingly investigated the possibility of incorporating end-of-life glass waste into gypsum materials, with particular emphasis on the use of recycled glass powder as reinforcement [1]. Research results indicate that gypsum reinforced with glass powder shows good mechanical and thermal properties similar to that reinforced with glass fibers [2,5]. Moreover, it has been found that specific properties of glass fibers extracted from discarded waste, such as their length and aspect ratio, significantly influence the mechanical and physical properties of the resulting gypsum, as highlighted by Majumdar, A. J.[3]

Utilizing recycled fibers is a great way to lessen the impact on the environment and the amount of garbage that ends up in landfills. Numerous studies have demonstrated the economic viability and feasibility of using various fiber types recovered from waste sources in the manufacturing of reinforced concrete [5,8,12]. High carbon steel strands and wires make up wire ropes, which can deteriorate due to a number of factors, including fatigue-induced inter-wire friction and corrosion [9, 17]. Understanding the stress behavior of individual wires is important, but it's also important to include the elevated stress resistance displayed by the insulated wire buried in the cable when estimating the overall behavior of the cable [18].

One statistical technique used to evaluate relationships between variables and identify meaningful differences between groups is the analysis of variance (ANOVA). It facilitates the estimation of statistical parameters and the understanding of the relative contributions of each source of variation to the observed overall variability. We may ascertain the statistical significance of these correlations and the impact of independent variables (factors) on dependent variables (responses) by using ANOVA. This makes it possible to fully comprehend the variables influencing the dependent variables as well as the reasons causing the observed variance [16,17, 18].

A comparison of the absolute relative percent error and desirability with the experimental data is necessary to validate the optimal design proportions obtained from the RSM model. This shows minimal values and demonstrating the precise forecast of the intended answers. This validates the RSM model's accuracy and dependability in making precise predictions for the designated design proportions. Furthermore, a graphical depiction known as the "ramp view diagram for optimization" is utilized to illustrate the optimization procedure and enable the assessment of the various factors' impacts on the intended result [18, 19].

And in order to gain a better understanding of the behaviour of local materials in the field of civil engineering and building construction. It is important to estimate their resources and study their physical, chemical, mechanical and thermal properties.

In this respect, the objective set in this work is the characterisation and valorisation of a local material which is the traditional plaster known as "Timchemt" and thus the improvement of the mechanical characteristics of Timchemt based bricks, studying the effect of the addition of glass powder in precise percentages, which vary up to 5%.

Three ideal parameters have to be used in order to validate the models that were developed. To guarantee the highest level of accuracy and dependability, a comparison between the absolute relative percent error and the attractiveness was also done, along with an evaluation based on the ramp view diagram.

MATERIALS AND METHODS

Materials

Gypsum (Timchemt)

Traditional plaster is burned in traditional ovens. These ovens are rudimentary constructions, built in thick timchent, vertical oven 1.5 m high and 1 m in diameter, and the second horizontal oven 1 m high and 4 m in diameter in a courtyard.For this a worker goes down into the hole and places a row of large blocks of temchemt around the bottom (wait in front of the opening).Then he places a second row, a little set back towards the centre, fills the sides with smaller pieces and climbs on this second seat; a third is placed in the same way and then, with a large block, the middle is blocked: in short, a vault has been built; the worker continues to fill the oven until it is above ground level, where it ends up in a dome, a dome almost one metre high in the centre, above ground level.The fire is then started: through the opening that connects the bottom of the oven with the trench, dry wood is introduced, the fire is started, when the fire is well established it is fed with branches of wood with the fibres of palm trees. This fire is maintained for 6 to 8 hours after it is broken up and crushed with a pestle, which is the traditional plaster (Timchemt).Figure. 1 illustrates the visual inspection of traditional ovens used for cooking temperature.

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Figure.1. Traditional ovens used for cooking (Timchemt)[5].

Tables 1 and 2 present a summary of the physicochemical properties of the gypsum (Timchemt) used. According to the NF P 94-068 standard, our sample is between 0.2 and 2.5mm, which means that it is not very adsorbent, not very plastic, and sensitive to water. The X'Pert High Score Plus software package was used to identify the compounds and phases of gypsum (Timchemt) after removing it from the kiln, as shown in Figure 2.

Table 1. Physical characteristics of gypsum (Timchemt) used.

Tests	Unit	Results
Apparent density	g/cm^3	1.39
Absolute density	g/cm^3	2.18
Methylene blue		0.68
Plasticity limit (W_L)		41.10
Liquidity limit (W_P)		34.42
Plasticity index (I_P)		6.68
Sand equivalent	%	38.8

Table 2. Chemical characteristics of gypsum (Timchemt) used.

Components	Percentage (%)
Insolubles	27
Ca S O4 (H2 O)	86
Cu2 Hg I4	41
Cu6 Zn3 As4 S12	69
Si O2	49
Pd F2	58
V3 In O7	61
SO_4^{-2}	16.93
$CaCO_3$	2
Cl^-	0.845

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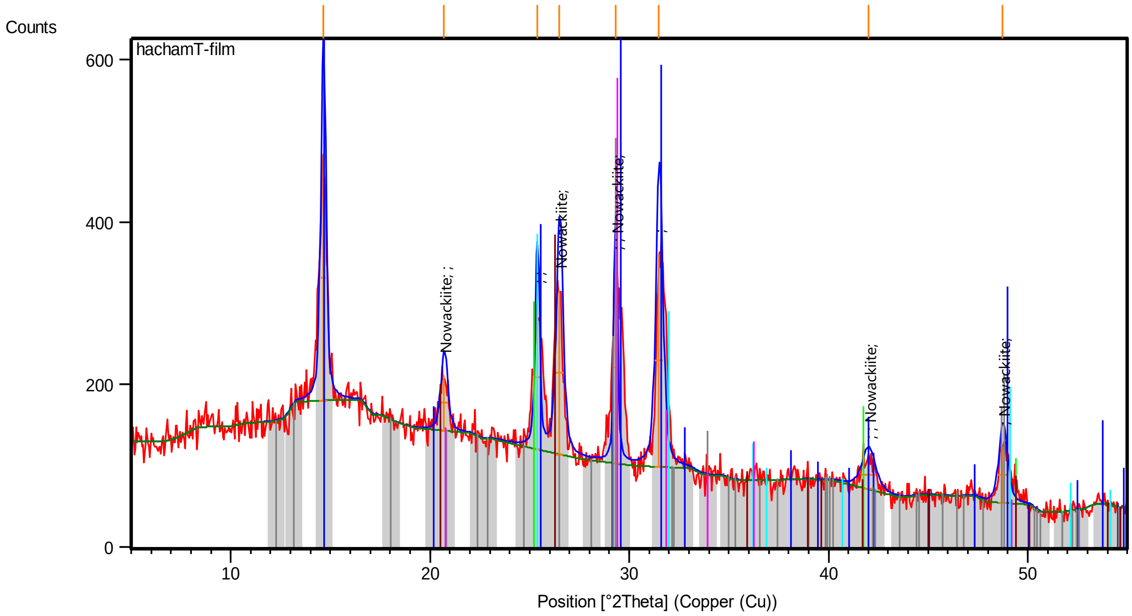

Figure. 2. XRD of gypsum (Timchemt)

Glass powder

Glass formers are the elements that can be converted to glass when combined with oxygen. Silicon dioxide (SiO_2), used in the form of sand, is the most common glass former. Ordinary glass contains about 70% SiO_2. Sodium carbonate (anhydrous sodium carbonate, Na_2CO_3) acts as a melting agent in the melt. It lowers the melting point and viscosity of the formed glass, releases carbon dioxide, and helps stir the melt[5].

Figure 3 details to obtain powder each bottle was then thoroughly cleaned, soaked, and rinsed to get rid of any dust, paper labels, and other undesired elements. After drying, they were ground and crushed using a machine known as the Los Angeles Machine. In order to achieve a homogeneous structure with few voids, the waste glass powder utilized had a particle size of 75 µm to match the particle size range of the binder (Timchemt).

Figure 3: the steps to obtain the glass powder

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The glass powder (GP) used in this study was obtained in the glass waste elimination area in Ouargla (southern Algeria). It has a density of 2.67 g/cm3 and a specific surface area of 2944 cm²/g and specific gravity 2.58 g/cm^3, Modulus of elasticity 72 GPa. The Table 3 is shown chemical properties.

Table 3 : **Chemical properties of Glass Powdre**

Compound	Percentage %
SiO_2	66.56
Al_2O_3	01.02
CaO	11.50
MgO	03.02
B_2O_3	02.45
Na_2O	10.32

Methods

Formulation method

Six mixtures of plaster bricks were prepared with two variables: gypsum (Timchemt) and glass powder. The Timchemt was used at 95%, 96%, 97%, 98%, 99%, and 100%. In addition, the glass powder (GP) content was 0%, 1%, 2%, 3%, 4%, 5%, and 6% of the mold volume (40*40*160) mm³, compliant with standard NF P 18-400.

These quantities have been optimized in order to obtain good thermal and mechanical properties. The content of gypsum (Temchemt) and glass powder of 1800 grams (1350 gr + 450 gr) for all the compositions of the mixtures studied. All samples were kept for 24 hours in the molds, then demolded and subjected to a curing period of 28 days in a temperature-controlled water bath in the laboratory control room, maintained at 20 °C, according to the standard NF P 18-404.

The mechanical resistance of the bricks with gypsum on the part of the prismatic specimens is (40x40x160) mm^3, according to the European norm EN 196-1. The thermal conductivity of the briquettes on the plates is fixed to the norm NF P 75–101. The combinations of all the mixtures that are in Table 4.

Dimensions of specimens

The molds used are made of gypsum reinforced by glass powder. The different dimensions of the specimens are: Prismatic: 70×70×280 mm 3 for the thermal test

Prismatic: 40x40x160 mm 3 for compressive strength, flexural tensile strength test (Figure 5).

Figure 5: the bricks tested

Compositions

Six different Mixtures were created using an experimental approach design to study the effects of wasted glass powder in gypsum. This set of mixes includes a control mix. A design mix of waste glass powder and gypsum is used to form a composite material. The design table 3 shows the relative mix and GP variable dosage.

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Table 4. Mixture proportions of gypsum and glass powder .

Mixture	gypsum (Timchemt) (%)	GP (%)	Timchemt (gr)	GP (gr)	Ratio Water / (Timchemt + GP)	Water (ml)
Mixture 1	100	0	1800	0	0.7	906.474
Mixture 2	99	1	1782	18	0.7	900.728
Mixture 3	98	2	1764	36	0.7	897.783
Mixture 4	97	3	1746	54	0.7	893.437
Mixture 5	96	4	1728	72	0.7	889.437
Mixture 6	95	5	1710	90	0.7	888.946

Result and Method

Method

Compression test

As per standard NF P18-406, the compression test involves shattering the test body between the two plates of a 2000 KN compression press (Figure 6).Once the specimen has been properly centered, the loading is started. The machine pauses at the point of failure, and we acquire the compressive stress that correlates to the breaking load.

Figure 6: Testing for compression by crush

traction by flexion test

In accordance with NF P. 18-407 norms, prismatic specimens (7×7×28) cm 3 are used for the bending test. It entails measuring the specimen's resistance to bending at three different sites after it is exposed to a central force applied with a hydraulic press (Figure 7).

Figure 7 : Flexural test

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Test Thermomechanical

Conductivity or thermal resistivity tests (TCT or TRT) are the investigation method that is highlighted. These tests provide physical information that characterizes the behavior of materials during heat transfer by conduction (thermal conductivity) on the fundamental basis of Fourier's law, which, according to the international system of units (SI), represents the quantity of heat transferred per unit area and per unit time under a temperature gradient (Figure 8).

Figure 8 : the thermal test

Thermomechanical properties of plaster brick

The results of the mechanical and thermal laboratory tests of the plaster brick are listed in Table 5.

Table 5. Experimental results.

Mixture	Timchemt (%)	Glass Powder (%)	Density (g/cm^3)	Flexural strenght at 28 days (MPa)	Compressive strenght at 28 days (MPa)	Thermal condictivity (W/m. k)	Thermal resistance (m^2.k/W)
Mixture1	100	0	1.45	0.84	1.67	0.32	0.48
Mixture2	99	1	1.44	1.24	2.2	0.29	0.52
Mixture3	98	2	1.41	1.56	2.5	0.29	0.52
Mixture4	97	3	1.402	1.84	2.8	0.28	0.54
Mixture5	96	4	1.38	1.84	2.69	0.26	0.58
Mixture6	95	5	1.38	1.24	2.15	0.26	0.58

Response Surface Methodology (RSM)
Model Development and ANOVA

The primary objective of utilizing Response Surface Methodology (RSM) in the early stages of experimental design (DOE) is to create predictive models for responses and facilitate optimization. These response models may manifest as either linear or higher-order polynomial equations, as exemplified in the generalized formats depicted in Equations **(1)** and **(2)**.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_n x_n + \epsilon \quad \textbf{(1)}$$

$$Y = \beta_0 + \sum_i^k \boldsymbol{\beta_i X_i} + \sum_i^k \boldsymbol{\beta_{ii} X_i^2} + \sum_{ij}^k \boldsymbol{\beta_{ij}. X_i. X_j} + \epsilon \quad \textbf{(2)}$$

where y denotes the desired response, β_0 is the regression coefficient for the constant term, whereas β_i, β_{ii}, and β_{ij} are the coefficients for linear, quadratic, and the interaction of x_i and x_j terms, respectively. The number of factors is denoted by k, while the random error is denoted by ϵ.

The tests were conducted using various mixtures of gypsum (Timchemt) and glass powder (GP), and the results were used to develop mathematical models. These models aimed to characterize the individual and combined influences of each variable on the characteristics of hardened plaster bricks, such as density, compression strength, flexural strength, thermal conductivity, and thermal resistance. The equations **(3)–(7)** represent quadratic mathematical models that have been derived using coded factors generated by statistical software (Expert design, Version 13).The generated models associate factors A and B with the following elements: A corresponds to gypsum (Timchemt), while B is related to glass powder (GP). It is crucial to emphasize that higher values for these factorial coefficients result in an amplification of the corresponding modeled response, while negative values indicate a decrease in the associated response.

$$\text{Density (g/cm}^3) = + 1.41 + 0.0384A + 0.00B - 0.0092AB + 0.00A^2 + 0.00B^2 \quad (3)$$
$$\text{Compressive strength at 28 days (MPa)} = +2.7 – 0.2979A+0.00B+0.7801AB+0.00A^2+0.00B^2 \quad (4)$$
$$\text{Flexural strength at 28 days (MPa)} = +1.75 – 0.2914A + 0.00B + 0.7009AB + 0.00A^2 + 0.00B^2 \quad (5)$$
$$\text{Thermal conductivity (W/m. k)} = + 0.2797 + 0.0286A + 0.00B – 0.0078AB + 0.00B^2 + 0.00B^2 \quad (6)$$
$$\text{Thermal resistance (m}^2\text{.k/W)} = + 0.5388 – 0.05B + 0.00B + 0.0045AB + 0.00A^2 + 0.00B^2 \quad (7)$$

According to the results from tables 6 and 7 of the ANOVA, it is clear that the produced models demonstrate a satisfactory relationship between the independent variables (A and B) and the responses (density, compressive strength, flexural strength, thermal conductivity, and thermal resistance).

Table 6. Analysis of variance (ANOVA) in the hardened state.

Source	Density, g/cm^3				Compressive Strength, MPa				Flexural Strength, MPa			
	Degrees of Freedom	Sum of Squares	F-Value	P-Value (Prob > F)	Degrees of Freedom	Sum of Squares	F-Value	P-Value (Prob > F)	Degrees of Freedom	Sum of Squares	F-Value	P-Value (Prob > F)
Model	2	0.0042	42.61	0.0063	2	0.8301	36.55	0.0078	2	0.7073	16.07	0.0249
A	1	0.0041	83.61	0.0028	1	0.2484	21.87	0.0185	1	0.2378	10.81	0.0462
B	0	0	-	-	0	0	-	-	0	0	-	-
AB	1	0.0001	1.62	0.293	1	0.5817	51.22	0.0056	1	0.4695	21.33	0.0191
A^2	0	0	-	-	0	0	-	-	0	0	-	-
B^2	0	0	-	-	0	0	-	-	0	0	-	-
Residual	3	0.0001	-	-	3	0.0341	-	-	3	0.066	-	-
Cor Total	5	0.0044	-	-	5	0.8641	-	-	5	0.7733	-	-
	Std. Dev	0.007	R^2	0.966	Std. Dev	0.1066	R^2	0.9606	Std. Dev	0.1483	R^2	0.9146
	Mean	1.41	Adj-R^2	0.9433	Mean	2.33	Adj-R^2	0.9343	Mean	1.43	Adj-R^2	0.8577
	C.V. %	0.4986	Pred-R^2	0.768	C.V. %	4.56	Pred-R^2	0.6768	C.V. %	10.40	Pred-R^2	0.1682
	PRESS	/	Adeq Pr	15.4556	PRESS	0.2793	Adeq Pr	14.6821	PRESS	0.6432	Adeq Pr	0.1682

Table 7. Analysis of variance (ANOVA) in the thermal state.

Source	Thermal condictivity (W/m. k)				Thermal resistance (m^2.k/W)			
	Degrees of Freedom	Sum of Squares	F-Value	P-Value (Prob > F)	Degrees of Freedom	Sum of Squares	F-Value	P-Value (Prob > F)
Model	2	0.0023	18.58	0.0204	2	0.007	20.47	0.0178
A	1	0.0023	36.23	0.0092	1	0.007	40.83	0.0078
B	0	0	-	-	0	0	-	-
AB	1	0.0001	0.9245	0.4072	1	0	0.1111	0.7608
A^2	0	0	-	-	0	0	-	-
B^2	0	0	-	-	0	0	-	-
Residual	3	0.0002	-	-	3	0.0005	-	-
Cor Total	5	0.0025	-	-	5	0.0075	-	-
	Std. Dev	0.0079	R^2	0.9253	Std. Dev	0.0131	R^2	0.9317
	Mean	0.2833	Adj-R^2	0.8755	Mean	0.5367	Adj-R^2	0.8862
	C.V. %	2.8	Pred-R^2	0.6437	C.V. %	2.44	Pred-R^2	0.7063
	PRESS	0.0009	Adeq Pr	10.1737	PRESS	0.0022	Adeq Pr	10.8012

Std. Dev: standard of deviation; C.V: coefficient of variation; PRESS: predicted residual error of sum of squares; Adj-R^2: R^2 adjusted; Pred-R^2: predicted R^2; Adeq Pr: adequate precision.

The results of the ANOVA indicate that the precision values of all models are greater than 4, demonstrating their ability to accurately represent the relationship between independent variables and responses. Furthermore, the results reveal a p-value lower than 0.05 for all examined parameters, suggesting that the models developed by the RSM method are statistically significant. The determination coefficients (R^2) obtained to assess the relevance of the models all exceed 91%, indicating a strong correlation between predictions and experimental observations. When the R^2 value approaches 1, the accuracy of the proposed model increases [11].

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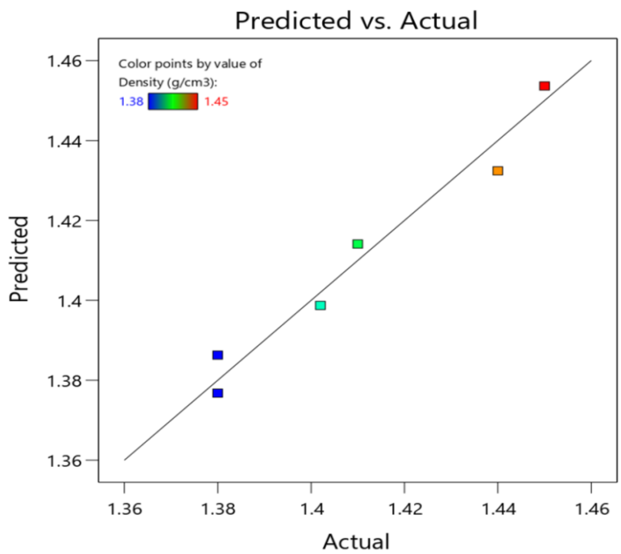
The F-values elevated by 42.61, 36.55, 16.07, 18.58, and 20.47, confirm the significance of the mathematical model for density, compression strength, flexural strength, thermal conductivity, and thermal resistance, respectively. The interactions (AB) are statistically non-significant (p-value > 0.05) for density, thermal conductivity, and thermal resistance, while the other linear terms (A and B) as well as the quadratic terms (A^2 and B^2) are significant (p-value < 0.05).

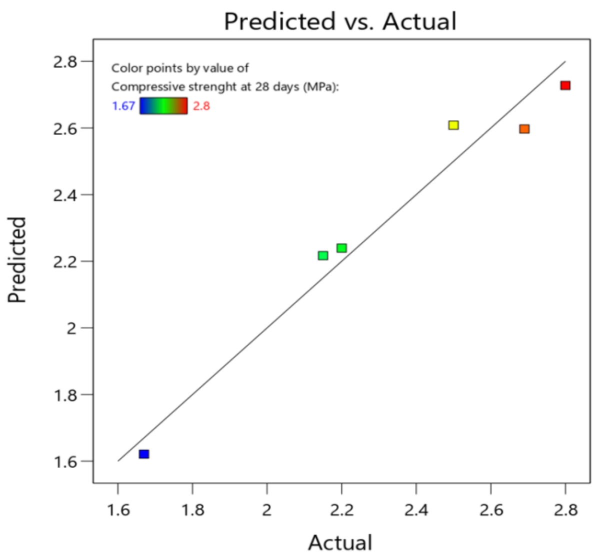
According to the distribution of experimental values compared to the predicted values illustrated in Figure 9, it is observable that the data points are very close to the fitting line. This suggests that the developed models are suitable for accurately predicting the thermomechanical properties of plaster bricks concerning the selected factors.

The perturbation diagram of the obtained models shows the changes in the Timchemt (%) and Glass Powder (%) factors, denoted as A and B, respectively, at the coded levels (-1 and +1) relative to the reference point (zero level "0"). It is important to note that a positive level of coded factors (+1) indicates maximum values, whereas indicating a negative level (-1) leads to minimum values of the factors.

The **Figure 10** indicates that factor (A) has a positive effect on density, while having a negative effect on compressive strength, flexural strength, thermal conductivity, and thermal resistance on the positive side (+1). On the other hand, there is a continuous stabilization of factor (B) on both the negative (-1) and positive (+1) sides.

Other vital tools used to assess the interaction between the variables are the model graphs, which include the 2D contour and the 3D response-surface diagrams. As shown in **Figures 11–14**, these plots are color-coded to show the influence of the interaction of the input factors on the responses. Red regions represent areas with high response intensity, while blue regions represent areas with low response magnitudes. The intermediate response values are represented by the yellow and green regions.
The results from Figure 11 illustrate that an increase in the Timchemt percentage, along with a reduction in the glass powder content from 5% to 0%, leads to high density values of up to 1.44 g/cm³[12].Figures 12 and 7 present 2D contour diagrams and 3D graphs to assess compressive strength and flexural strength at 28 days. These figures reveal a significant increase in compressive strength and flexural strength at the maximum and minimum levels of Timchemt and glass powder[13].However, Figures 14 and 15 suggest that using a Timchemt percentage of approximately 95%, along with varying the glass powder content from 0% to 5%, results in very high levels of thermal conductivity and thermal resistance[14].





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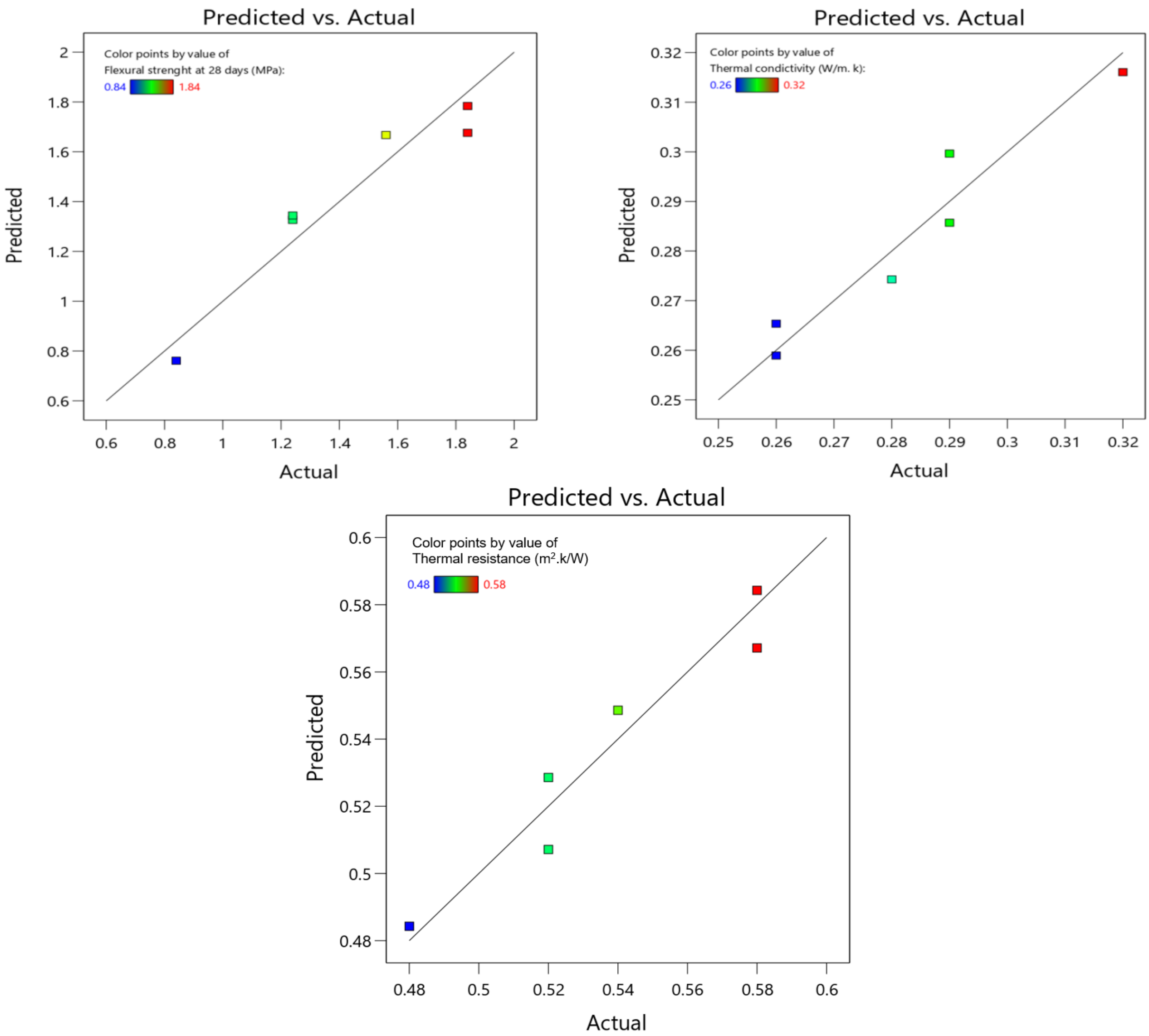
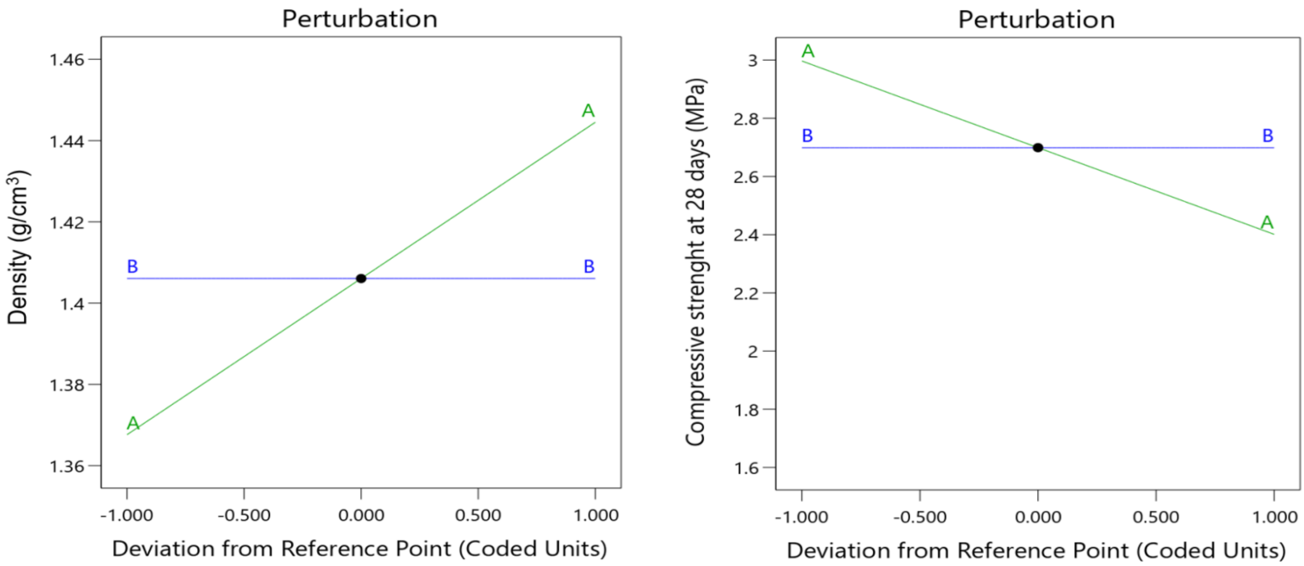


Figure 9. Probability distribution plot of: Density ; compressive strength at 28 days; flexural strength at 28 days; Thermal conductivity; Thermal resistance.



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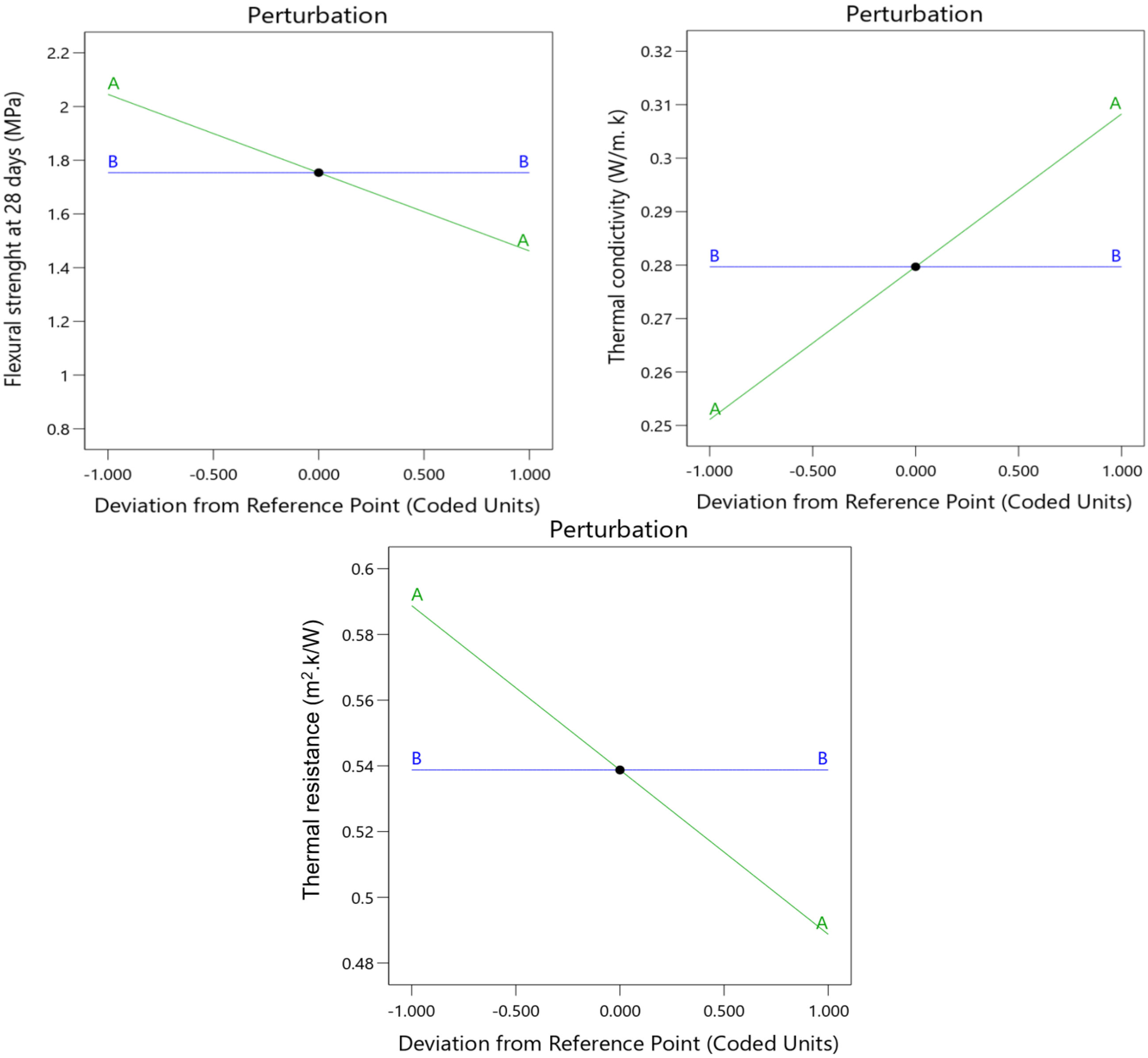

Figure 10. Perturbation plot for: Density ; compressive strength at 28 days; flexural strength at 28 days; Thermal conductivity; Thermal resistance

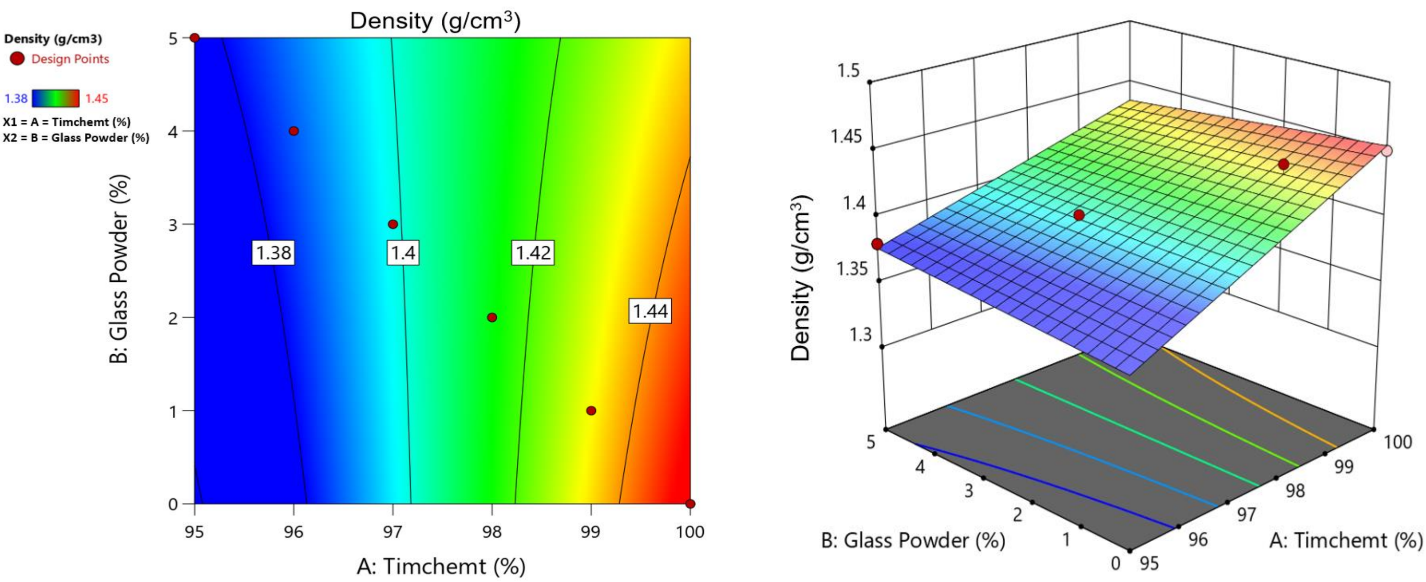

Figure 11.RSM analysis diagrams for density.

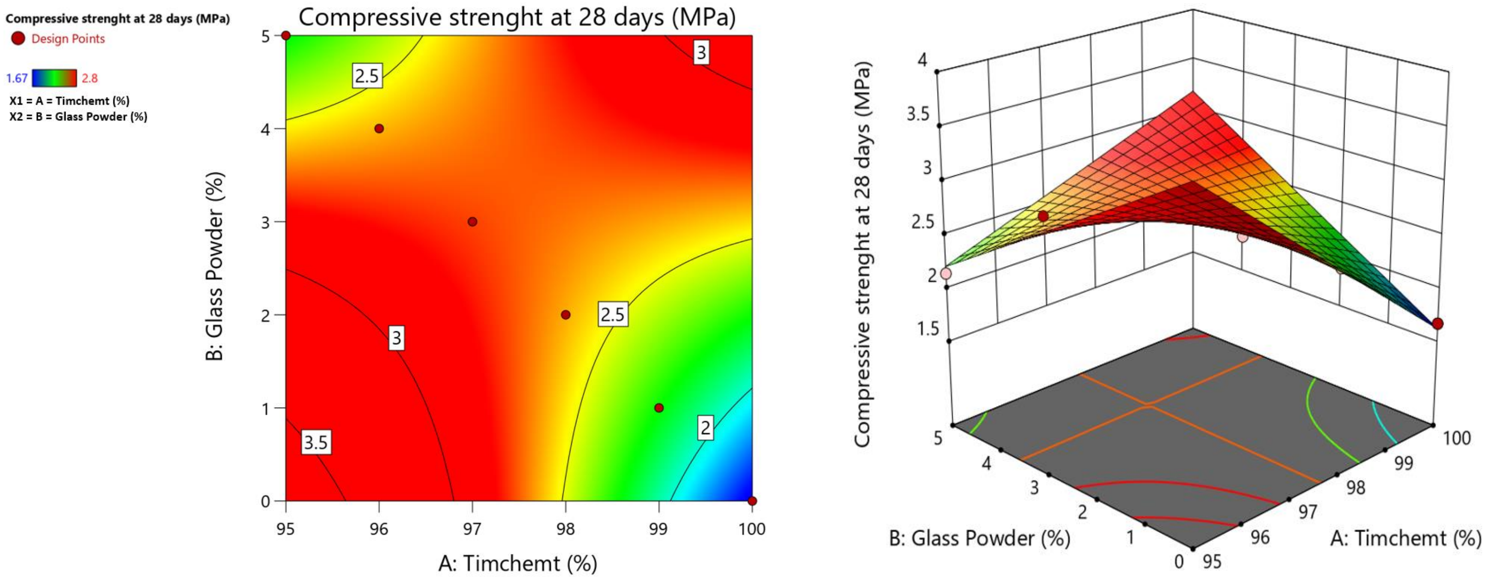

Figure 12.RSM analysis diagrams for compressive strength.

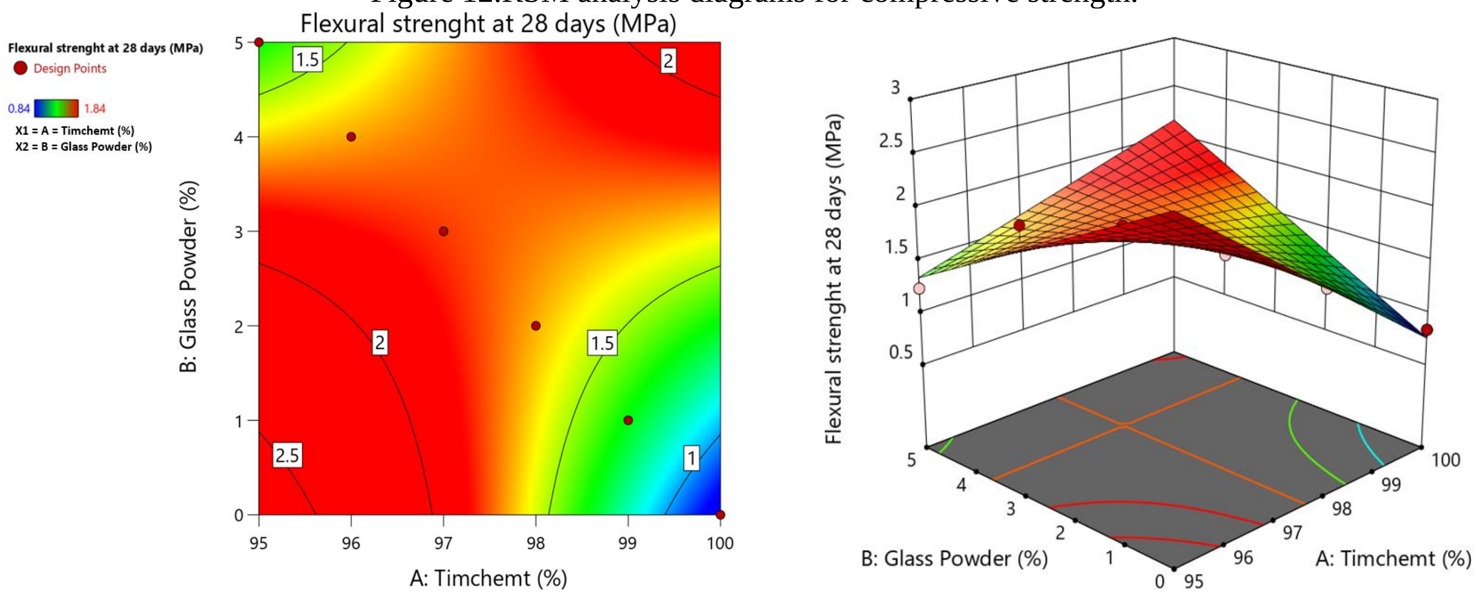

Figure 13. RSM analysis diagrams for flexural strength.

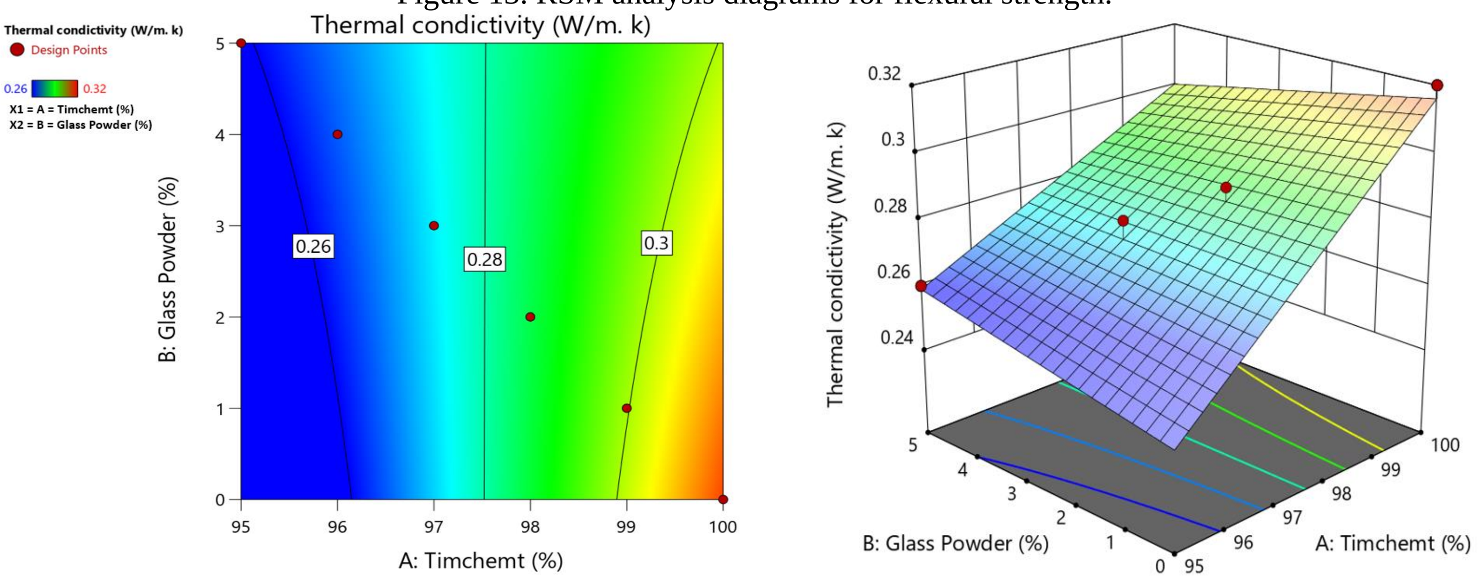

Figure 14.RSM analysis diagrams for thermal condictivity.

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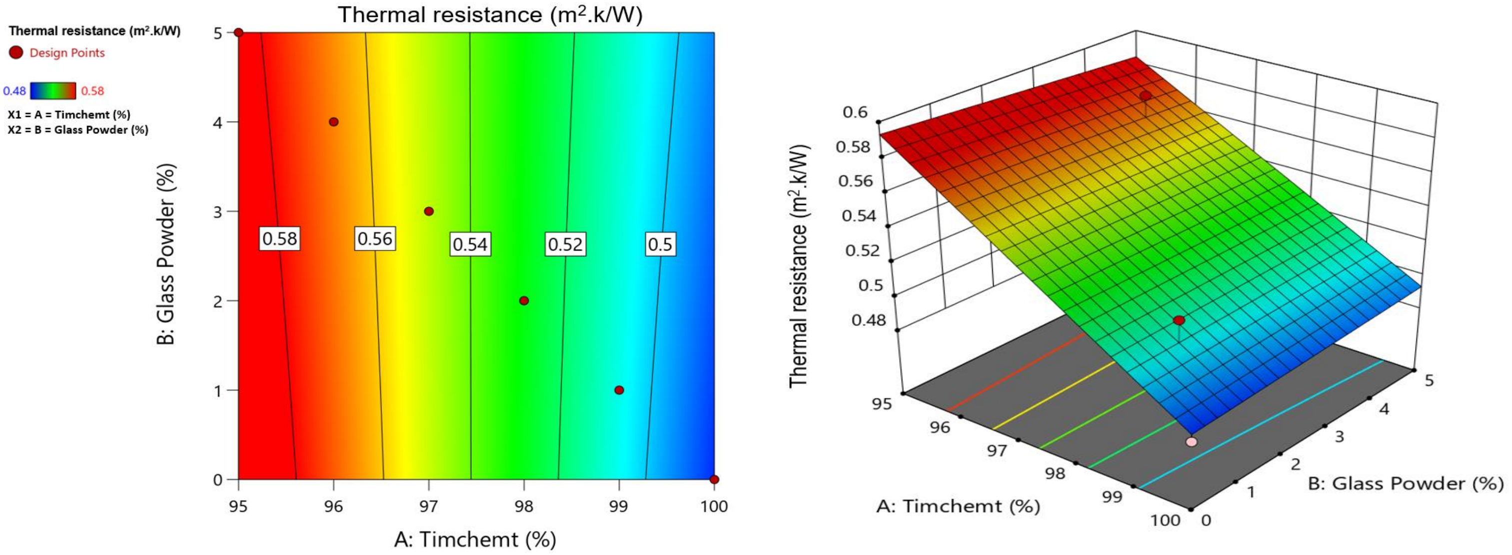

Figure 15. RSM analysis diagrams for thermal resistance.

Optimization and Experimental Validation

An effort at optimizing the system is made to discover what values of the independent variables should be used to attain the highest possible level of the response of interest. Attaining the objective function may be completed by creating objectives for the variables (input factors and responses) that have various criteria and degrees of relevance. When evaluating the optimization, the desirability value, which ranges from 0 to 1, is used. The closer the value is to one, the more favourable the result [28].

Table 8 presents the optimization objectives and objective functions applied in this study. We have chosen the objectives of glass powder content "97.5%" and Timchemt content "2.5%" so that they correspond to the range of experimental values. The system has been configured to maximize density, compression strength, and flexural strength while minimizing thermal conductivity and thermal resistance.

The final phase of the RSM analysis involves experimentally validating the conclusions by conducting trials with samples, using the optimal proportions of the identified variables. These samples were subjected to tests to assess their responses after a period of 28 days. The results, along with the optimal predictions, are presented in Table 8. Equation (8) was applied to calculate the experimental error (PE) for a comparison between the two sets of results, which are also summarized in Table 8. The values of experimental error (PE) associated with all responses are below 12%, demonstrating the accuracy of the optimization and developed response models.

$$\text{Absolute relative percent error (PE), \%} = \left(1 - \frac{\textbf{Predicted value}}{\textbf{Experimental value}}\right) \times 100 \qquad (1)$$

Table 8. Experimental validation of the studied models.

Parameters	Unit	Goal	Model Prediction	Laboratory Experiment	PE (%)	Desirability
Timchemt	%	Target	97.5	97.5	-	-
Glass Powder	%	Target ->	2.5	2.5	-	-
Density	g/cm^3	Maximum	1.41224	1.38	2.33	0.969 (96.6 %)
Compressive strenght at 28 days	MPa	Maximum	2.69906	2.58	4.61	0.728 (72.8 %)
Flexural strenght at 28 days	MPa	Maximum	1.75375	1.69	3.77	0.970 (97 %)
Thermal condictivity	W/m. k	Minimum	0.279687	0.25	11.87	0.876 (87.6 %)
Thermal resistance	m^2.k/W	Minimum	0.534368	0.49	9.05	0.747 (74.7 %)

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After the optimization process, the results indicate that the optimal values for density, compression strength, flexural strength, thermal conductivity, and thermal resistance are 2.69 g/cm³, 1.41 MPa, 1.75 MPa, 0.27 W/m·K, and 0.53 m²·K/W, respectively. These values can be achieved by maintaining the optimal levels of 97.5% and 2.5% for Timchemt and glass powder, respectively. The optimization criteria aim to achieve desirabilities of 72.8%, 96.9%, 97%, 87.6%, and 74.7% for density, compression strength, flexural strength, thermal conductivity, and thermal resistance, respectively. The optimization solution is graphically represented as ramps in Figure 16, while the 3D response surface diagrams of desirability are presented in Figures 17.

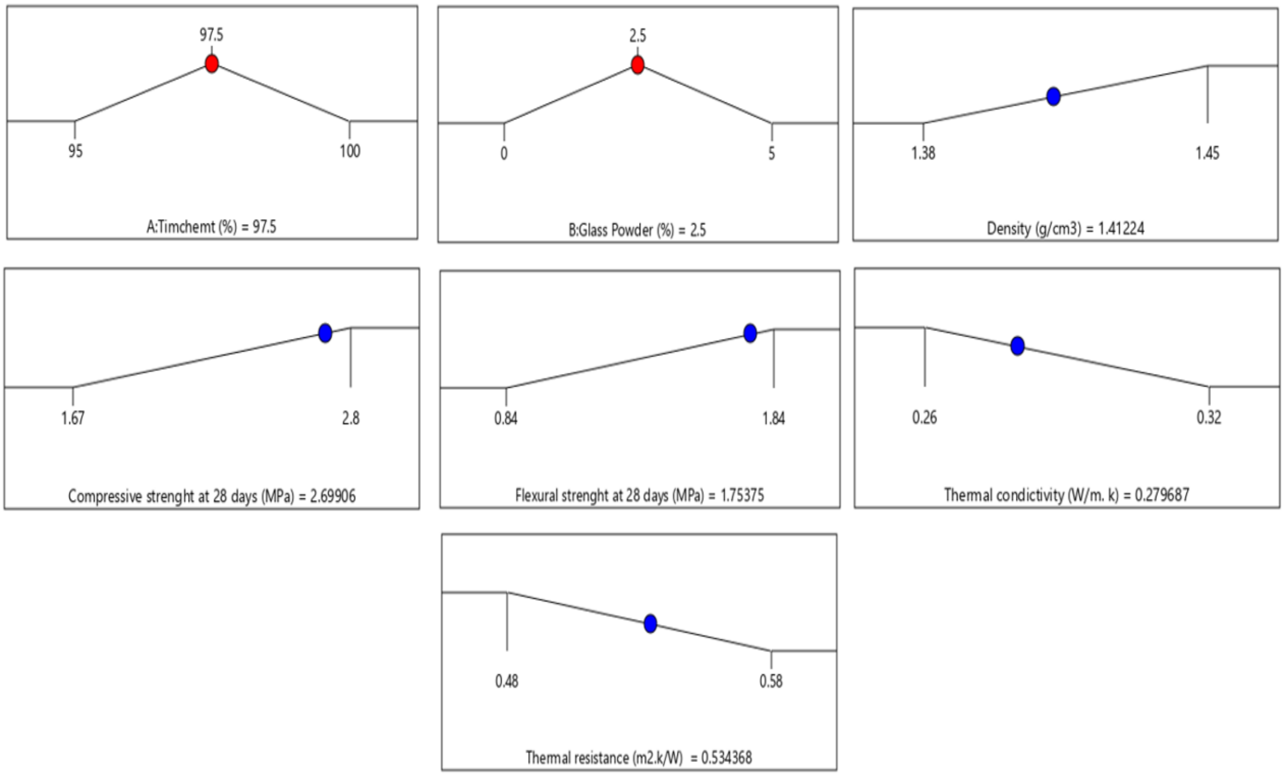
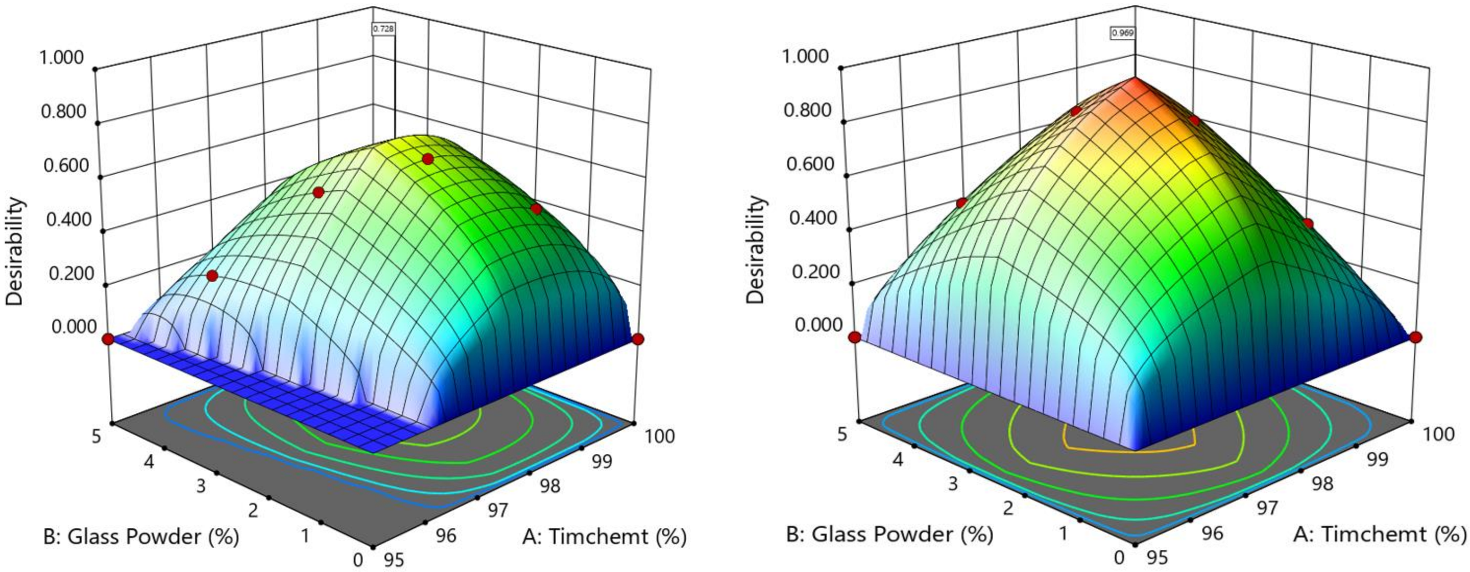


Figure 16. Ramp view diagram of optimization.



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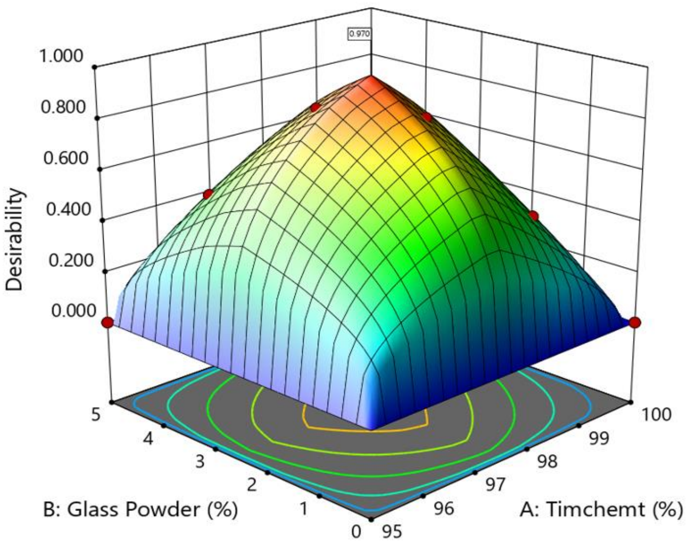
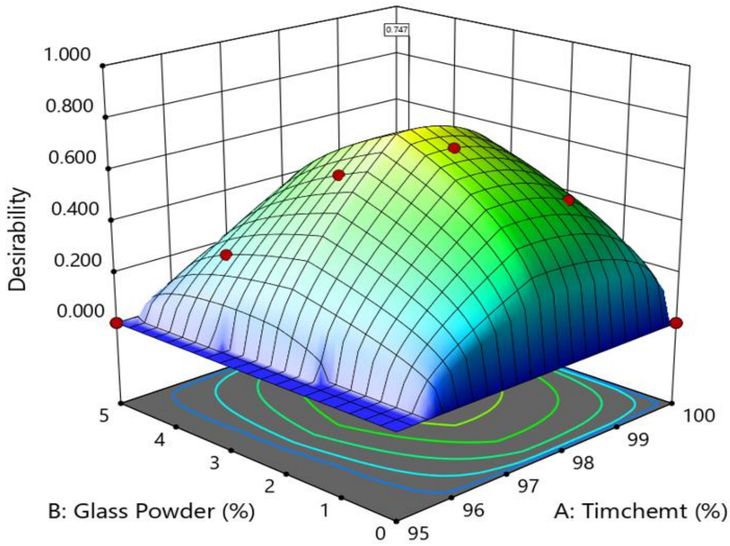
(a)Density

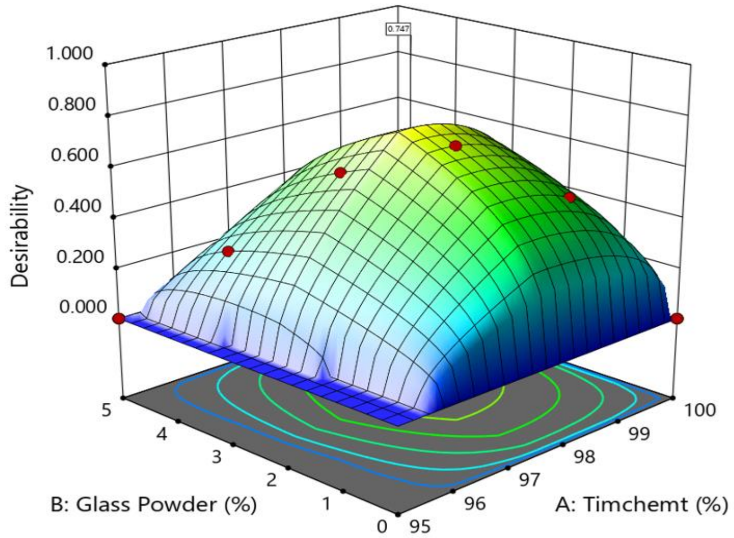
(b)Compressive strenght





(c) Flexural strength

(d) Thermal condictivity

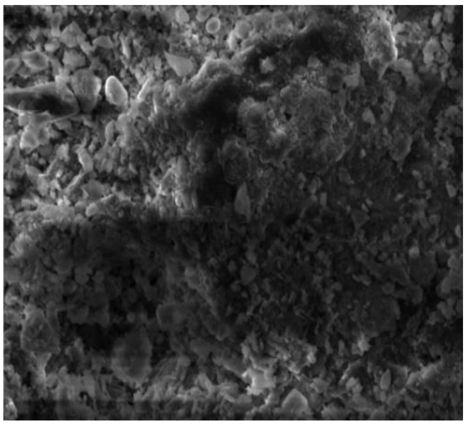


(e) Thermal resistance

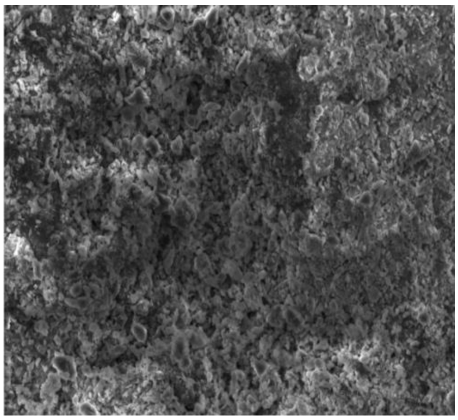
Figure 17. 3D response surface plot for the optimization desirability.

Microstructure of plaster brick

Figure 18 represent the scanning electron microscopic (SEM) analysis of the mixture of plaster brick.



(a)



(b)

Figure. 18.Scanning electron micrograph (SEM) of plaster brick mixtures at magnifications of (× 1000).

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CONCLUSION

The objective of this experimental study was to evaluate the thermomechanical behavior of plaster bricks by developing mixture design models incorporating glass powder (GP). Based on the results obtained, the following conclusions can be drawn from this research:

- The use of the RSM model has demonstrated its high predictive efficiency in determining thermomechanical characteristics through the following factors: Timchemt (%) and glass powder (%). This method significantly reduces the time and resources required for repeated laboratory experiments.
- The results of the analysis of variance (ANOVA) highlight the effectiveness of the models created to capture the correlation between independent variables and their associated responses.
- Examination of the probability distribution of the experimental data confirms the reliability of the models developed to estimate accurately.
- The Perturbation graphs provide a detailed analysis of factors (A and B) in relation to the reference point on the range of coded parameters (-1, 0, +1).
- The increase in the Timchemt percentage, along with a reduction in the glass powder content from 5% to 0%, leads to high density values of up to 1.44 g/cm³.
- These 2D contour diagrams and 3D graphs reveal a significant increase in compressive strength and flexural strength at the maximum and minimum levels of Timchemt and glass powder.
- The decreases factor of Timchemt approximately 95%, along with varying the glass powder content from 0% to 5%, results in very high levels of thermal conductivity and thermal resistance.
- The significant implication of the low (PE) values reveals that the experimental measurements exhibit an absolute relative error of less than 12% and a correlation coefficient surpassing 88%. This finding indicates that the RSM model accurately and precisely predicted the desired responses.

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