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Research Paper

Face Centered-Central Composite Design Technique in Modeling the Effects of Delay after Mixing On the Elastic Modulus of Metakaolin Modified Black Cotton Soils

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ABSTRACT
The concept of delay in compaction after mixing on the characteristics of modified soils have been studied in recent years, most especially on traditionally modified soils. This study seeks to model the effect of this phenomenon on the elastic modulus of black cotton soils modified using metakaolin (MK). Hence, this study is aimed at using the face centered-central composite design technique of the response surface methodology to model the effects of delay in compaction after mixing on the elastic modulus of MK modified black cotton soil. Elastic modulus of MKmodified black soil samples were determined from the tensile strength of the samples through appropriate experimental procedures. Elastic modulus optimization model was developed using response surface methodology (RSM) and then validated using R^2 statistics. 3D surface plots and ANOVA statistics were used to check the significance of compaction delay and other factors, together with their interactions on the elastic modulus of MK -black soil mix. From the analysis of the results, the developed RSM elastic modulus optimization model proved adequate with a R^2value of over 70% and can thus, be satisfactorily adopted in predicting and monitoring the influence of compaction delay on the elastic modulusof MK-black cotton soils. Compaction delay and its interactions with other constituents had a higher significance in comparison to other interactions. Furthermore, from the response optimization process using RSM with desirability function, four combinations werechecked for limitations of compaction delay effects. The combinations include; 48.1173% MK, 20% water with compaction delay not exceeding 132 minutes (2 hours, 12 mins); 15.8124%MK, 20% water with compaction delay not exceeding 92.7273 minutes; 11.2121%MK, 20% water with maximum compaction delay of 110.2460 minutes and lastly, 28.1818% MK, 20% water, with maximum compaction delay of 65.4545 minutes giving maximum value of 1626.9092 MPa for elastic modulus.

Keywords; *Elastic modulus, central composite design, Metakaolin, response surface methodology*.

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I. INTRODUCTION

The black cotton soils are highly plastic clayey soils having high swelling nature and have proved to be very problematic for the construction of various infrastructures like embankment, pavements, foundation, hydraulic barriers etc. The black cotton soils contain the Montmorillonite as a clay mineral, which causes the swelling nature in soil, due to water bond between the particles of soil. The alternate swell and shrink in the black cotton soil, due to wet and dry season, causes the differential settlement in the structure founded on them. This results to the structural damage of the structures in the form of micro cracks on its surfaces. [1]revealed that the variation in the volume properties of expansive soil occurs due to variation in the seasonal moisture content. [2]revealed that the black cotton soil causes the annual structural damage of about $1000 Millions in USA, £150 UK, and many billions pounds in worldwide. The expansive nature of black cotton soils have made it virtually impossible for it to be used as a foundational material for superstructures. The traditional way of taking care of this problem has always been to cart away the black cotton soils to a required depth and replace with a new foundational material possessing excellent properties. This practice can be sometimes very expensive with the disposal of the undesirable soil material also contributing to the problem. Of more recent practice, is remedying and improving the existing weak soil material. Correct remedial measures are to be adapted to modify the soil or to decrease its hazardous effects if expansive soils are identified in a project. Many stabilization systems are in practice for bettering the expansive soils where the traits of the soils are altered. This study throws more insight into the usage of metakaolin (MK) for the black cotton soil enhancement process.

1.1 Elastic Modulus of soils

The modulus of Elasticity of an engineering material is the stress per unit strain of that material. The soil modulus of elasticity is a fundamental parameter in understanding and estimating the volume change behavior of expansive soils associated with variations of environmental conditions ([3]; [4]). It is therefore one of the most important soil properties in geotechnical engineering design of both substructures and superstructures constructed in or on expansive soils. To conduct a reliable geotechnical design and analysis, it is often desirable to effectively describe the soil modulus of elasticity as a function of its influencing parameters.

The modulus of elasticity of soils depends on numerous parameters, such as (i) the initial level of compaction (dry unit weight or void ratio), (ii) the initial state hydration (water content, degree of saturation or matric suction) and (iii) the confinement (deviator stress or lateral stress). The other factors that affect the modulus of elasticity include variables such as boundary conditions, Poisson’s ratio, sample dimensions, soil structure (the size of soil particles), stress path and stress history, to list a few. The influence of all these parameters should be considered for a reliable estimation of the soil modulus of elasticity. However, accounting for the influence of all these parameters requires extensive experimental programs and multi-variable regression analyses. Such an approach is cumbersome to implement in conventional geotechnical engineering practice. Due to this reason, the modulus of elasticity of unsaturated soils has been expressed in the literature as a function of only one or two parameters.

[5]and[6] proposed a power function to quantitatively describe the relationship between the soil modulus of elasticity and the soil water content. [7]used a semi-empirical model for estimating the modulus of elasticity of unsaturated expansive soils as a function of the matrix suction changes, neglecting the influence of mechanical stress changes. Investigators such as [8], have linked the modulus of elasticity to a change in both the net normal stress and the matrix suction using multiple regression methods; such an approach is rigorous but is time consuming from the view point of conducting various experimental studies. This study seeks to model the elastic modulus of modified soils using metakaolin against the constituent materials of the modified soil mix and also considering the compaction delay factor.

1.2 Compaction Delay Effects on Modified Soil Properties

Under field conditions, a delay between the mixing process and compaction is usually unavoidable. Earlier research has established that the effects of delay in compaction is more noticeable when the mixture is left undisturbed than when it is intermittently mixed ([9]).

In recent times, the importance of delay recorded between mixing/placing of modified soils and actual compaction have been given thorough attention. There have been a handful of researches on the effect of compaction delay on the properties of stabilized soils. Some of these researches are hereby highlighted.

Some researchers ([10], [11]; [12]) worked on lateritic soil with respect to elapse time after mixing. From work done on the effects of elapsed time on the properties of cement –bagasse ash modified black cotton soil, it was observed that both cohesion and angle of internal friction decreased with increase in elapsed time between mixing and compaction. For the modification of black cotton soil, it was recommended that an optimal blend of 4% ordinary Portland cement/4%bagasse ash be used. Based on shear strength parameters consideration, the elapsed time between mixing and compaction was recommended not to exceed 2 hours.

[13]carried out a study of the effect of elapsed time on the geotechnical properties of lime – bagasse ash stabilized black cotton soil. An optimal 6% lime/8% bagasse ashtreatment of black cotton soil when compacted with British Standard heavy energy was recommended. Furthermore, the delay between mixing and compaction should not exceed one and half hours.

[14]carried out a study on the effect of elapsed time after mixing on baggase ash modified black cotton soil. it was reported that an optimal value of 4 % Baggase ash be adopted for treatment of black cotton soil and compacted with British Standard heavy energy. This optimal combination is recommended for use as a sub-grade material of lightly trafficked roads and a maximum elapsed time of 2 hours after mixing should not be exceeded.

1.3 Central Composite Design of the Response Surface Methodology

The Response surface methodology (RSM) is an empirical statistical and mathematical tool used to explore the relationship between several independent or explanatory variables and one or more dependent or response variables [15]. The relationships are provided in a list of descending order of desirability which represents the closeness of a response to its ideal value. The desirability is dimensionless and lies between 0 and 1. The greater a desirability value, the more a response falls within the ideal intervals. RSM uses a sequence of designed experiments to determine an optimal set of variables in order to obtain the desired response. The effect of an individual variable can be assessed while the other variables are varied [16], which take advantage over the usual observatory comparison analysis. The RSM has been widely applied in other field of engineering and more recently in civil engineering [17].

RSM usually uses two approaches to develop mix design and explore response models. They are central composite design (CCD) and Box-Behnken design (BBD). CCD uses an optimal number of experiments to derive the relationships between the variables [18]. CCD consists of 2^n factorial runs, 2n axial runs and $n_c$centre runs, where n is the number of variables in the experiment and can range between 3 and 10 [15]. CCD is further categorized into; circumscribed CCD, face-centered CCD and inscribed CCD. In face-centered CCD (Figure 1), axial points are located at a distance from the center point, i.e., at the face of the design cube, fora three factor experimental design.Centre runs replicate a centre point experiment and can be set between 2 and 6. The CCD processes the experiment results and yields a response model in the form of Equation (1).

$$Y = f\left(X_{1,} X_{2,} X_{3,} \ldots\ldots X_n\right) \pm e \qquad (1)$$

Where,

Y = response of the experiment
X_i = the independent variables
e = the experimental error

The function, f is unknown and may be complex, based on the relationship between the variables and the response. Therefore, RSM aims at identifying a suitable polynomial relationship between the variables and the response surface (i.e. the best fit surface). In some cases, a higher-order polynomial, such as a quadratic model, may be applied and Equation (1) becomes;

$$Y = \beta_0 + \sum_{i=1}^{n}(\beta_i X_i) + \sum_{i=1}^{n}(\beta_{ii} X_i^2) + \sum_{i=1}^{n}\sum_{j=1}^{n}(\beta_{ij} X_{ij} X_i X_j) + e \qquad (2)$$

Where,

$\beta_0$is a constant, β_i is a linear coefficient, β_{ii} is the quadratic coefficient and β_{ij} is the interaction coefficient.

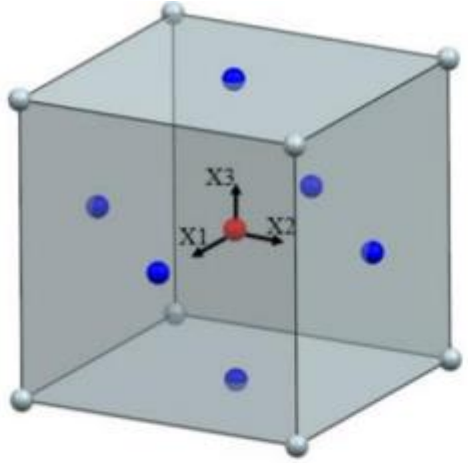


Figure 1. Face-Centered Central Composite Design for Three Factor Design

II. MATERIALS AND METHODS

The properties of the black cotton soil used in this study are displayed in Table 1 which was modified using metakaolin (MK). MK properties and class is presented as shown in Table 2.

Table 1. Properties of Black cotton soil

Item	Value (description)
Specific gravity	2.61- representative of a fine grained material.
Plasticity index	5.56%- a fine grained soil material with low plasticity
AASHTO classification	A-4 (sandy-silty soil material)
Grain distribution	
Clay	6.3%
Silt	75%
Fine sand	11.1%
Medium and Coarse sand	7.6%
Compaction characteristics	
Optimum moisture content (OMC)	14.5%
Maximum dry density (MDD)	1.98 g/cm^3

Table 2. Metakaolin Properties

Item	Value (description)
Specific gravity	2.28
Sum of acidic oxides	91.3%
ASTM Classification	Class N pozzolan

1.4 Experimental Mix Design Development (Face-Centered Central Composite Design)

In building the mix design using the face-centered CCD of RSM, experience and information from literature were used. MK content was limited to 10-50% by weight of dry black cotton soil. Because the optimum moisture content of black cotton soil is 14.5%, water content was varied between 10-20% by weight of MK-black cotton soil mix. Furthermore, compaction delay was included as a factor that influences the elastic modulus of MK-black cotton soil with the range kept at 0-180 minutes. This results to a three experimental factor design where the factors are; MK dosage, water/modified soil ratio and compaction delay. The face-centered central composite design for the three factor experimental design is thus displayed in Table 3.

1.5 Elastic Modulus Determination

The splitting cylinder test was used as the measure of the indirect tensile strength in this study. This splitting cylinder test was determined in accordance to ASTM C496 [19]. The indirect tensile strength was evaluated mathematically using Equation (3).

$$\sigma_t = \frac{2P}{\pi D t} \quad (3)$$

Where; P is equivalent to the failure load, D is the diameter or width of the MK-black soil specimen and t represent the thickness.The tensile strength in combination with the tensile strain obtained from this test was then used to obtain the elastic modulus of the modified black cotton soil sample.

2.3 Response Surface Model Development

For a three factor design, Equation (2) according to the RSM, becomes;

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \quad (4)$$

Where,

Y = response, which in this study represent the elastic modulus of MK –black cotton soil

X_1 = MK dosage, as a percentage proportion of dry black cotton soil

X_2 = Water/MK-soil ratio, as a percentage proportion of MK modified black cotton soil

X_3 = Delay in compaction in minutes

$\beta_0$is a constant, β_i is a linear coefficient, β_{ii} is the quadratic coefficient and β_{ij} is the interaction coefficient, which are to be calibrated or determined.

Due to the mathematical complexities involved with determination of the model (Equation 4) coefficients, MINITAB statistical software was employed for model calibration.

2.4 Model verification/validation

Elastic modulus optimization model developed in this study was verified in two ways;

1. The model and the experimental results were plotted on the same graph to examine the level of agreement between both results.
2. Reliability tests using ANOVA statistics- which test the goodness of fit and significance of the developed model was also conducted

Table 3. CCD of MK-black cotton soil constituents' proportions

StdOrder	RunOrder	PtType	Blocks	MK dosage (%)	Water/modified soil (%)	Compaction delay (mins)
24	1	1	1	50	15	180
7	2	1	1	10	20	0
4	3	1	1	10	15	0
16	4	1	1	30	20	0
11	5	1	1	30	10	90
17	6	1	1	30	20	90
18	7	1	1	30	20	180
6	8	1	1	10	15	180

25	9	1	1	50	20	0
13	10	1	1	30	15	0
19	11	1	1	50	10	0
15	12	1	1	30	15	180
27	13	1	1	50	20	180
22	14	1	1	50	15	0
3	15	1	1	10	10	180
8	16	1	1	10	20	90
5	17	1	1	10	15	90
10	18	1	1	30	10	0
2	19	1	1	10	10	90
26	20	1	1	50	20	90
1	21	1	1	10	10	0
21	22	1	1	50	10	180
14	23	1	1	30	15	90
20	24	1	1	50	10	90
12	25	1	1	30	10	180
9	26	1	1	10	20	180
23	27	1	1	50	15	90

III. Results And Discussion

Table 4 presents the tensile characteristics of MK modified black cotton soils obtained from experimental procedures. Information from Table 4 was used in the development or calibration of Equation (4) model coefficients. The effect of compaction delay on the elastic modulus of MK modified black cotton soil was conducted using RSM 3D surface plots and ANOVA statistics.

Table 4. Tensile characteristics of MK-black cotton soils

S/N	Metakaolin (MK)	Water	Compaction delay (mins)	T. LOAD (N)	T.STRESS(MPa)	T. STRAIN	ELASTIC MODULUS (MPa)
1	50	15	180	352	0.02801	0.000051	546.811
2	10	20	0	506	0.04026	0.000045	888.567
3	10	15	0	638	0.05076	0.000035	1431.581
4	30	20	0	792	0.06302	0.000039	1599.421
5	30	10	90	396	0.03151	0.000049	639.768
6	30	20	90	902	0.07177	0.000032	2276.953
7	30	20	180	594	0.04726	0.000037	1262.701
8	10	15	180	462	0.03676	0.000041	888.567
9	50	20	0	484	0.03851	0.000041	930.880
10	30	15	0	616	0.04901	0.000039	1243.994
11	50	10	0	308	0.02451	0.000053	460.739
12	30	15	180	506	0.04026	0.000043	928.957
13	50	20	180	528	0.04201	0.000045	927.201
14	50	15	0	572	0.04551	0.000035	1283.486
15	10	10	180	286	0.02276	0.000057	398.323
16	10	20	90	660	0.05251	0.000032	1666.064
17	10	15	90	418	0.03326	0.000047	703.449
18	30	10	0	440	0.03501	0.000045	772.667

19	10	10	90	352	0.02801	0.000049	568.683
20	50	20	90	572	0.04551	0.000037	1215.934
21	10	10	0	550	0.04376	0.000041	1057.818
22	50	10	180	220	0.01750	0.000061	286.635
23	30	15	90	594	0.04726	0.000039	1199.566
24	50	10	90	308	0.02451	0.000049	497.598
25	30	10	180	352	0.02801	0.000053	526.558
26	10	20	180	528	0.04201	0.000043	969.346
27	50	15	90	506	0.04026	0.000041	973.193

3.1 Elastic Modulus RSM Optimization Model

The response surface model for the prediction and optimization of the elastic modulus of MK-black cotton soil is obtained as given by Equation (5) which is in the form of Equation (4). Equation (5) is capable of predicting the elastic modulus of MK-black cotton soil given any proportion of the MK-black cotton soil constituents with compaction delay considered as a key factor and vice versa.

$$EM\ (MPa) = -669 + 34.4MK + 148W - 0.58CD - 0.723\,MK^2 - 3.23W^2 - 0.0211CD^2 + 0.275MK * W + 0.0096MK * CD + 0.152W * CD \qquad (5)$$

Where;
EM = elastic modulus of MK-black cotton soil in MPa
MK = MK proportion in the modified soil mix
W = water content as a proportion of the modified black soil.
CD = compaction delay in minutes

3.2 Elastic modulus optimization model validation

Equation (5) representing the elastic modulus optimization model for MK-black cotton soil was validated in this section using the two methods stated in section 2.4. The model p-value of 0.003 displayed in Table 5 already tells how significant the optimization model is. This p-value (0.003) is far less than the α-value of 0.05 (5%), indicating that the elastic model (Equation 5) is significant. To further buttress the significance of the model, model or predicted elastic modulus values were plotted against experimental or observed values (Figure 2). Excellent agreement between the two sets of values can beobserved.

Furthermore, a reliability test − analysis of variance (ANOVA) which tests the fitness and significance of this model was also conducted. The test provided a R^2 of 0.7163. The R^2 value is not far away from 1 and thus suggest the excellent agreement between the predicted and observed results.

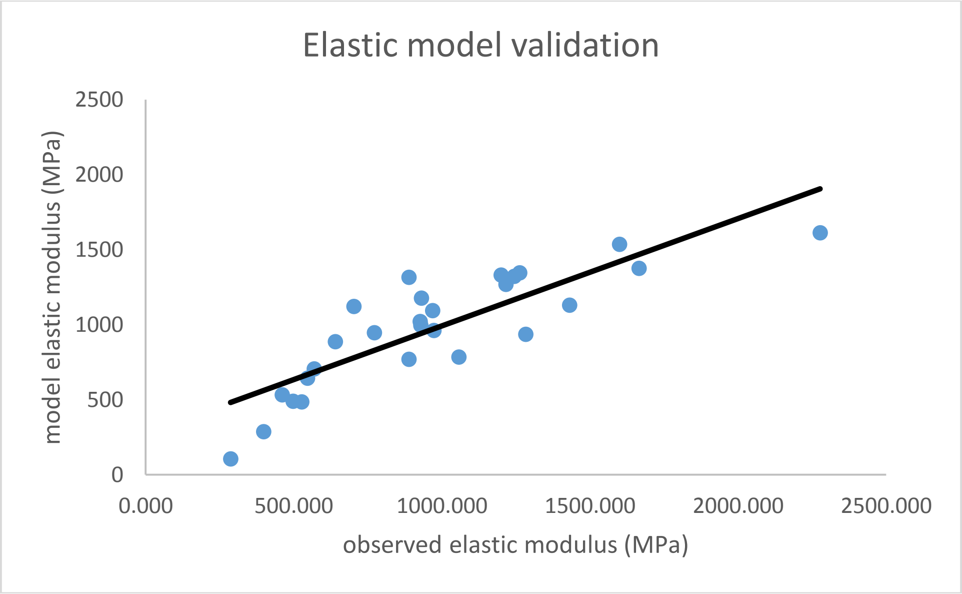


Figure 2. Model versus observed elastic modulus values

3.3 Effect of MK and Compaction delay on Elastic Modulus of MK-black cotton soil

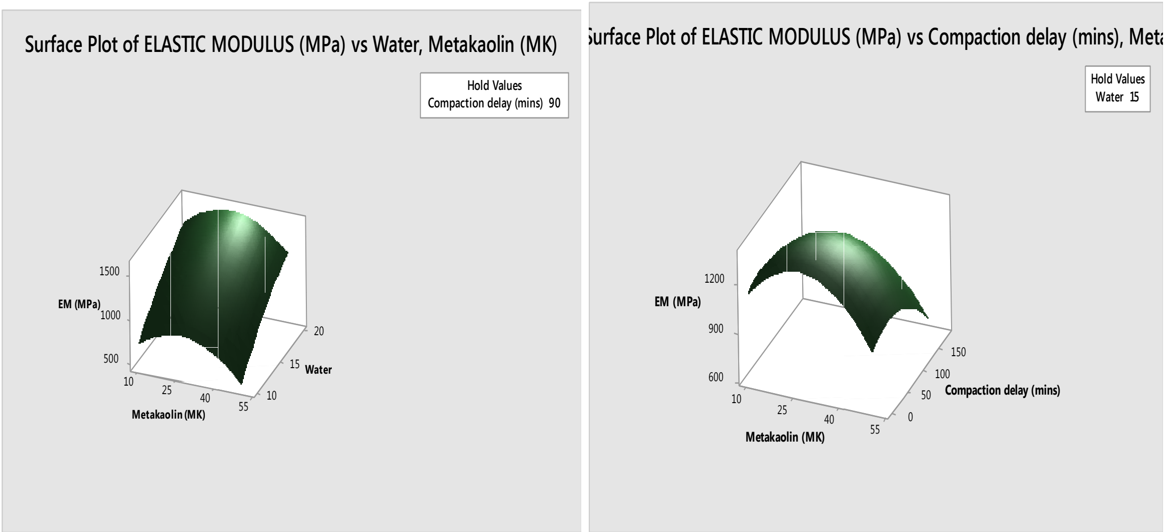
Effect of MK and its interactions on the elastic modulus of modified black cotton soil

The 3D surface plots of elastic modulus as it is affected by variation of metakaolin (MK) and its interaction with other components of modified black cotton soil mix is presented in Figure 3. In Figure 3a, compaction delay was fixed at 90mins in order to study the interaction of MK and water contents variation on the elastic modulus of MK-black cotton soil. As can be observed from Figure 3a, increment of MK content, has a quadratic effect on the elastic modulus of modified black cotton soil. That is, as the MK content increases, the elastic modulus also increased to an optimum MK content beyond which, noticeable decrease in elastic modulus is observed. As can also be observed, the elastic modulus of the modified black cotton soil increases by an independent increase in the water content (Figure 3a).The quadratic effect is again noticed when MK interacts with water in the modified black cotton soil mix. That is, when both factors are increased together, with compaction delay kept constant, the elastic modulus increases to an optimum point of interaction and then begin to decrease when this optimum point is exceeded.

In another vane, as can be noticed from Figure 3b, the interaction between MK and compaction delay with water content kept at 15%, leads to a negative effect on the elastic modulus of MK modified black cotton soil. That is, as the MK content in the soil increases at a fixed water content, delay in compaction should be discouraged as a negative effect is noticed on the elastic modulus of the modified soil mix.

The information given by the 3D surface plots in terms of how elastic modulus is affected by MK and its interaction with other modified black soil factors is qualitative in nature. ANOVA statistics presented in Table 5 was used to quantitatively rate and rank the effect of all factors and their interactions on the elastic modulus of MK-black cotton soil. This rating is done with reference to their associated p-values. The significance of a factor is inversely proportional to its p-value, that is, the smaller the p-value, the greater its influence or significance. From the p-values, generally, independent effect of the factors has a higher influence on the elastic modulus as given by the p-value of 0.000. This is followed by the square interaction effects of factors (factors interacting with itself) with a p-value of 0.076. Two way interaction effect of factors (interaction between one factor and another) had the least significant on elastic modulus with a p-value of 0.852.

Although MK has the least significant value in comparison to water and compaction delay as it affects the elastic modulus of modified black cotton soil, a p-value of 0.263 is also relatively significant. Moreover, for the square interaction of factors, MK has the highest significant effect on the elastic modulus of MK-black cotton soil mix with a p-value of 0.028.



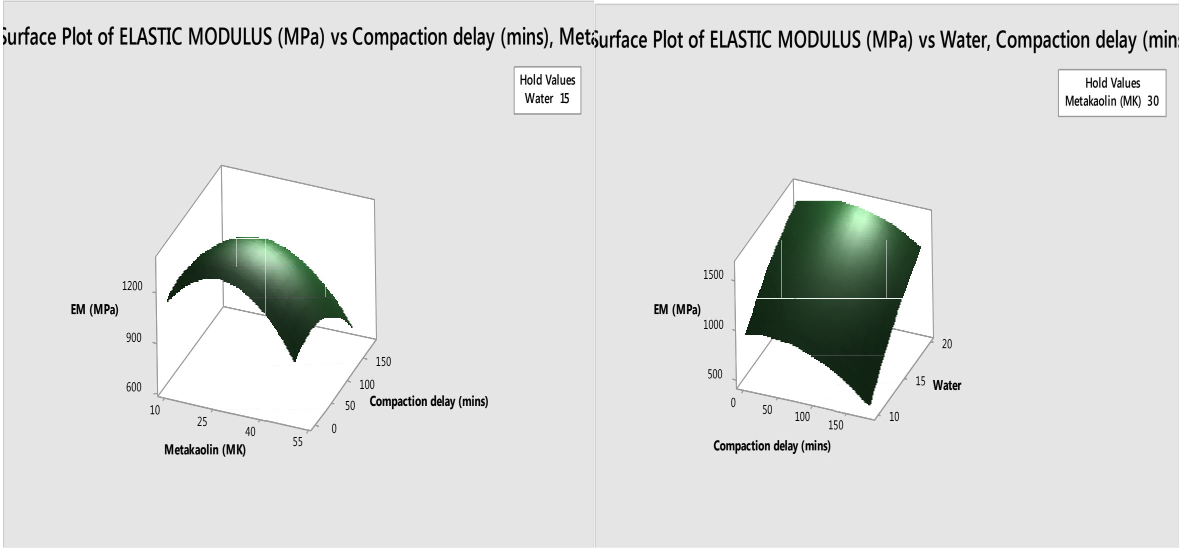
a. MK and W b. MK and CD

Figure 3. Surface plots of elastic modulus vs MK, water, compaction delay

Effect of **Compaction delay** *and its interactions on the elastic modulus of modified black cotton soil*

Figure 4 present the effect of compaction delay and its interactions on the elastic modulus of MK-black cotton soil. An independent increase in compaction delay negatively affects the elastic modulus when a particular delay time is exceeded (Figure 4).Interaction betweenMK and compaction delay tends to negatively support the elastic modulus as stated earlier in the previous sub section (Figure 4a). From Figure 4b which shows the interaction of compaction delay and water at a fixed MK content of 30%, increment in water content supports the delay in compaction at least to some certain extent or degree. That is to say, as the water content increases with the MK kept constant, delay can be encouraged in the scenario of the water content getting too much. This delay will lead to loss in water content, thereby, making the MK-black cotton soil to achieve desired strength and elastic properties.

Furthermore, as revealed by Table 5, compaction delay has a high level of significance with the independent p-value (0.032) below the threshold p-value (otherwise called the α-value of 0.05). This shows that the elastic modulus or tensile properties of MK-black cotton soil is greatly affected by the compaction delay experienced. On its interaction with other constituents, the compaction delay is not as significant as p-values of 0.842 and 0.434 were recorded for its interaction with MK and water respectively.



a. CD and MK b. CD and W

Figure 4. Surface plots of elastic modulus vsCompaction delay, MK, water

Table 5. ANOVA Statistics Showing the significance level of Factors and their Interactions on the elastic modulus of MK-black cotton soil

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	3747971	416441	4.77	0.003
Linear	3	2962742	987581	11.31	0.000
Metakaolin (MK)	1	116793	116793	1.34	0.263
Water	1	2367689	2367689	27.12	0.000
Compaction delay (mins)	1	478260	478260	5.48	0.032
Square	3	716535	238845	2.74	0.076
Metakaolin (MK)*Metakaolin (MK)	1	501955	501955	5.75	0.028
Water*Water	1	39115	39115	0.45	0.512
Compaction delay*Compaction delay	1	175465	175465	2.01	0.174
2-Way Interaction	3	68694	22898	0.26	0.852
Metakaolin (MK)*Water	1	9069	9069	0.10	0.751
Metakaolin (MK)*Compaction delay	1	3580	3580	0.04	0.842
Water*Compaction delay (mins)	1	56045	56045	0.64	0.434
Error	17	1484192	87305		
Total	26	5232163			

3.4 Limiting the Effects of Compaction Delay on the Elastic Modulus of MK-Black Cotton Soil

Equation (5) being the optimization model for elastic modulus was used in optimizing or limiting the effect of compaction delay on the elastic modulus of MK-black cotton soil. Response optimizer with desirability function was adopted for the optimization and/or limitation process.

Before the optimization process proper, contour plots were constructed for the different interactions involved. The optimal ranges obtained from this procedure aided in the optimization of the elastic modulus of MK-black cotton soil.

Figure 5 presents the contour plots for elastic modulus as it is affected by compaction delay and its interaction with other factors. A close study of Figure 5, for an elastic modulus range of 1250-1500MPa, the factors combination ranges are; 16-37% MK, 14-20% water, with compaction delay not exceeding 120minutes (2 hours). For an elastic modulus bracket of 750-1000MPa, the factor ranges expand to; 10-48% MK, 12-20%

water, with compaction delay allowed to about 178 minutes. Having obtained the maximum optimal elastic modulus range as 1250-1500MPa, optimization and/or limitation was conducted in four dimensions; left boundary phase- targeting 1250MPa, right boundary phase-targeting 1500MPa, mid point-targeting 1375MPa and lastly general optimization-maximizing the elastic modulus. Performance of response optimization process, is controlled by the desirability value or function. This desirability value is usually between 0-1, and the closer the value is to 1, the more reliable the optimization process.

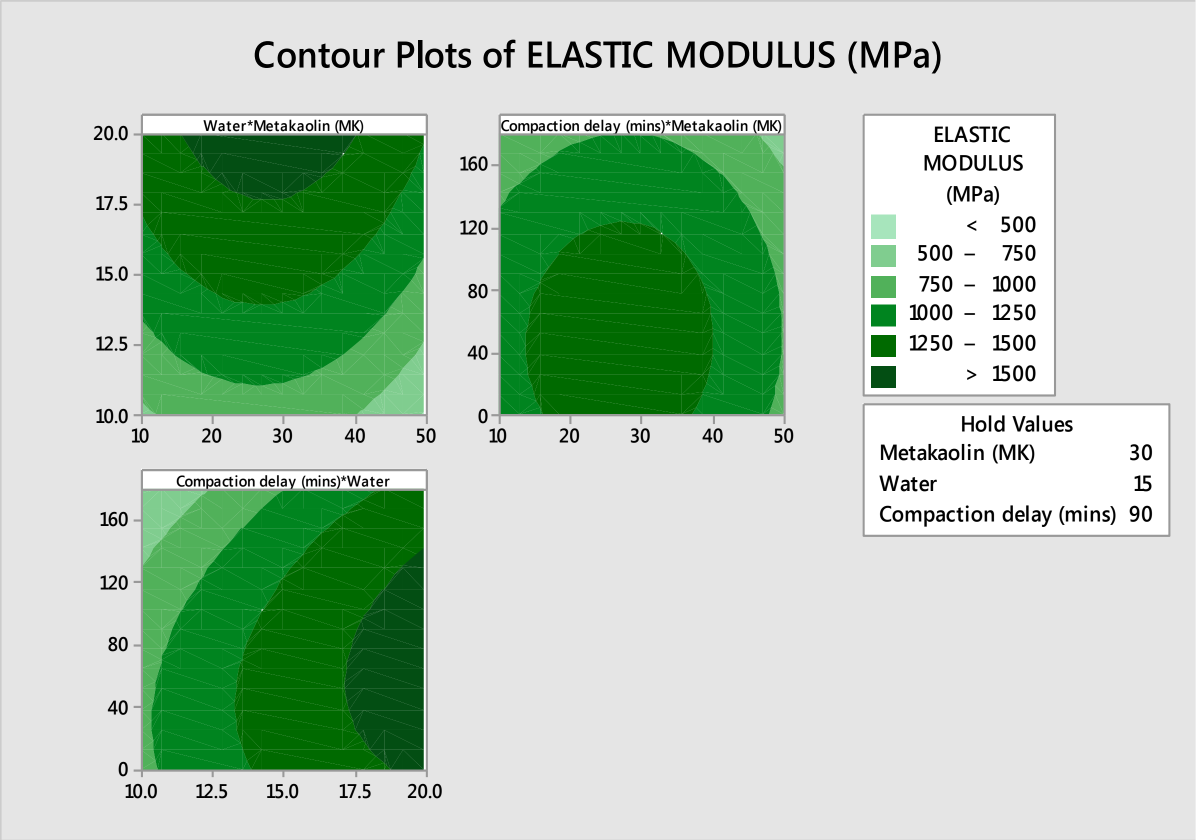


Figure 5. Contour plots of elastic modulus

Left boundary limitation

Figure 6 shows the left boundary optimization process where the elastic modulus value of 1250MPa was targeted at a compaction delay not exceeding 120 minutes. For this optimization process, the overall desirability value, D is 0.9995 (EM = 1249.4838 MPa). Because the desirability value is very close to 1, the optimization process can be considered adequate with factor combination of; 48.1173% MK, 20% water with compaction delay not exceeding 132 minutes (2 hours, 12 mins).

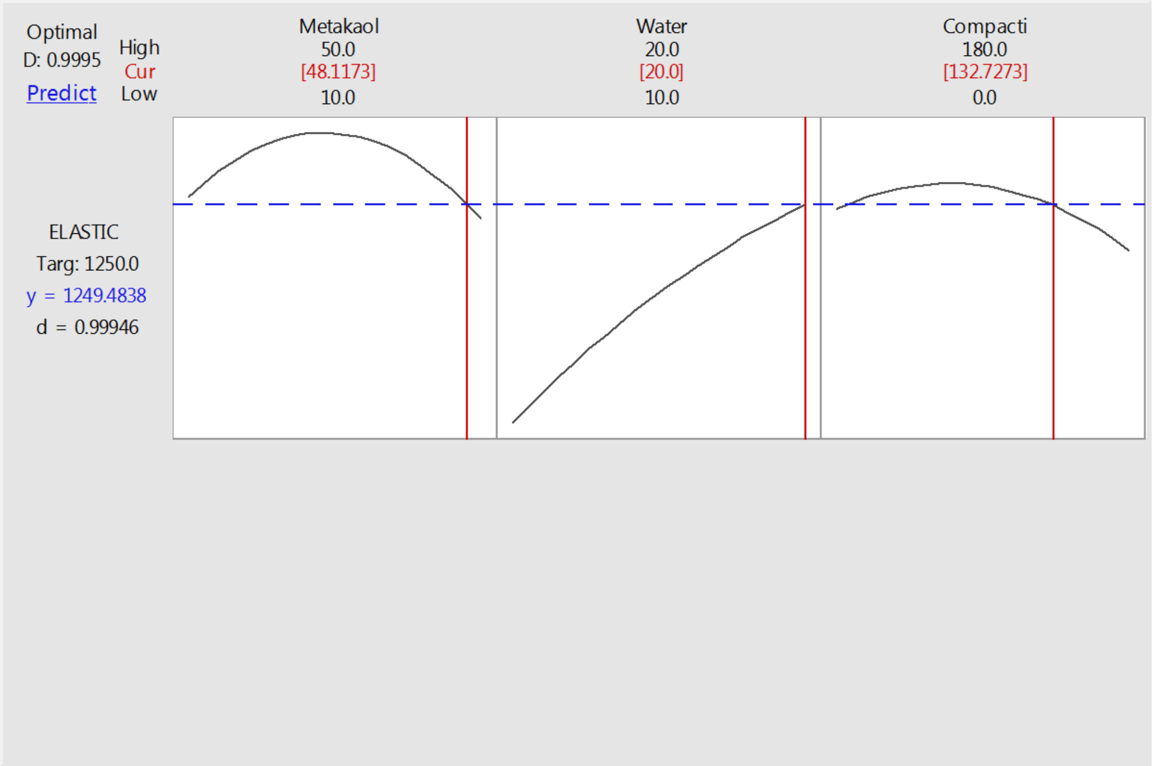


Figure 6. Left boundary response optimization of MK-black cotton soil elastic modulus

Right boundary limitation

The right boundary optimization process where elastic modulus value of 1500MPa is targeted is presented by Figure 7. Here, the D-value for the process was obtained as 0.9997 with elastic modulus of 1499.6421 MPa obtained. The factor combination obtained here is; 15.8124%MK, 20% water with compaction delay not exceeding 92.7273 minutes.

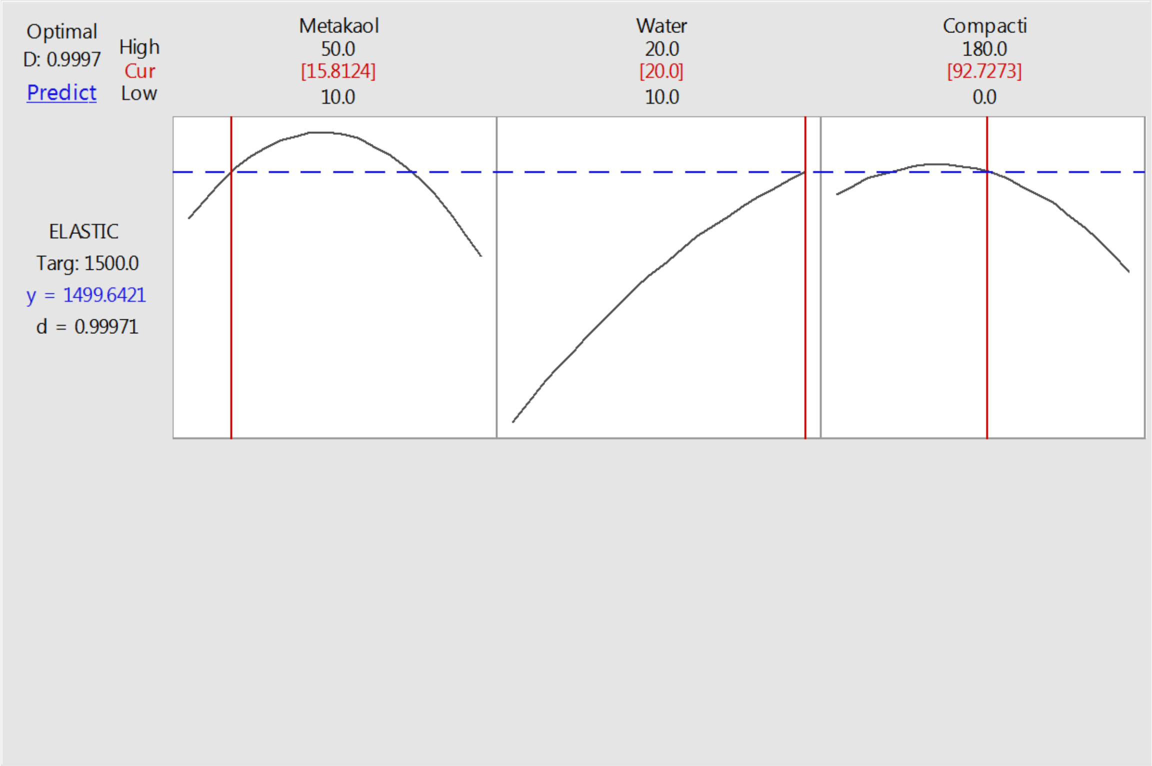


Figure 7. Right boundary response optimization of MK-black cotton soil elastic modulus

Mid-point limitation

For the mid-point process where elastic modulus value of 1375MPa is targeted, the result is presented by Figure 8. The D-value for the process here was obtained as 0.9972 with theelastic modulus value obtained as 1371.9543MPa. The factor combination obtained here is; 11.2121%MK, 20% water with maximum compaction delay of 110.2460 minutes.

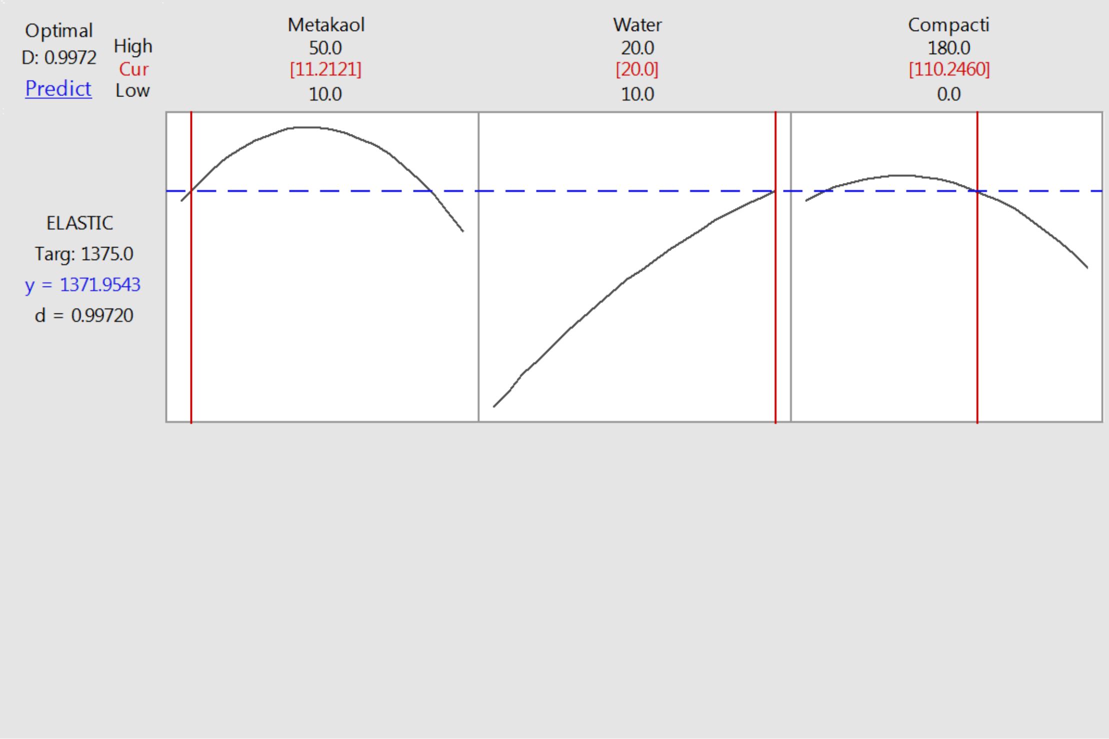


Figure 8. Mid-point response optimization of MK-black cotton soil elastic modulus

General limitation

In the general optimization process (Figure 9), maximum value of 1626.9092 MPa was obtained for elastic modulus. The desirability value for this optimization process is 0.6734 which is although low in comparison to the D-values of other process, is still within acceptable limit. The factor combination here is; 28.1818% MK, 20% water, with maximum compaction delay of 65.4545 minutes.

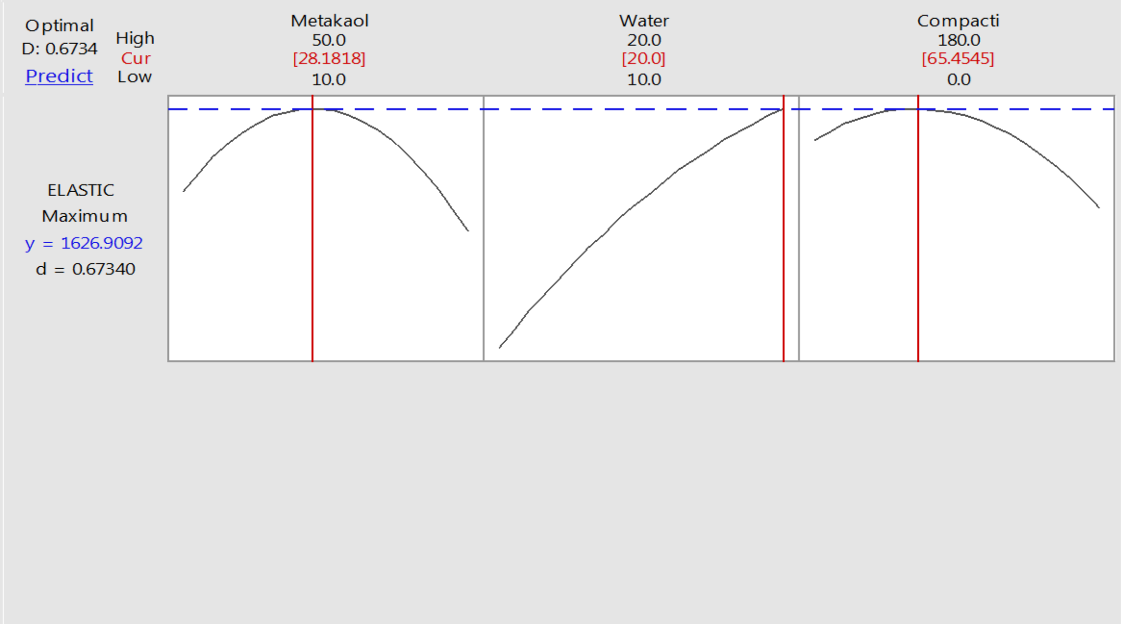


Figure 8. Mid-point response optimization of MK-black cotton soil elastic modulus

IV. CONCLUSION

The response surface optimization model developed for predicting the elastic modulus of MK-black cotton soil proved adequate at 5% significance level from the validation analysis carried out.

MK variation on the elastic modulus of black cotton soil reveals that the elastic modulus is significantly affected by the variation of MK content as a modifier.The independent effect of the factors has a higher significance on the elastic modulus as compared to the square and two factors interaction. Although MK has the least significant value on the elastic modulus of modified black cotton soil in comparison to water and compaction delay, its effect is also significant. Compaction delay factor and its interaction on other factors generally had more significance on elastic modulus of MK-black cotton soils as compared to the other two factor interactions. This is evident from the low p values it recorded as compared to the p-values of other two-way interactions. The highest of its interactions with constituents of the MK-black cotton soil mix was noticed at water-delay interaction closely followed by MK-delay interaction. This can be attributed to the fact that as soon as water is added to the soil-modifier mix, the hydration begins to take place and it is therefore desirable to compact as soon as mixing is completed. If compaction is not done as quickly as possible, the cementing effects of the MK would be lost leading to a considerable and significant increase in compaction delay effects on the moduli properties of the MK-black cotton soil mix. This is in concordance with different studies ([20]; [10]) carried out on the effect of compaction delay on the properties of modifier-soil mix.

RSM contour plots produced optimal ranges of factors combination for desirable elastic modulus of MK-black cotton soil. Focusing on the highest range of elastic modulus produced from RSM contour plots, elastic modulus optimization for the limitation of compaction delay revealed four possible factor combinations in the desirable range of elastic modulus; the left boundary revealed a factor combination of; 48.1173% MK, 20% water with compaction delay not exceeding 132 minutes (2 hours, 12 mins); the right moduli boundary revealed a factor combination of; 15.8124%MK, 20% water with compaction delay not exceeding 92.7273 minutes.; the mid point revealed, a factor combination of; 11.2121%MK, 20% water with maximum compaction delay of 110.2460 minutes and lastly, a general optimization which revealed a factor combination of 28.1818% MK, 20% water, with maximum compaction delay of 65.4545 minutes giving maximum value of 1626.9092 MPafor elastic modulus.

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