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THE IMPACT OF COARSE FRAGMENT CHARACTERISTICS ON COMPACTION BEHAVIOUR OF FINE GRAINED SOILS

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Abstract

A study was initiated to study the impact of soil rock content, rock size and rock strength on the compaction characteristics of two base soils. The treatment combinations encompassed two base soils (T1=silty clay and T2 =silty clay loam); rock strength (R1= 17.6, R2= 67.4 and R3= 119 MPa); rock size (S1=4.75 – 9.5 mm and S2 = 9.5 – 20 mm) and rock content (L1=0%; L2=5 %; L3 = 12.5%, L4=25%%; L5 = 37.5% and L6 =50%). The results indicated that the maximum dry density (MDD) of the soil rock mixture (SRM) increased linearly with an increase in soil rock content under most of the treatment combinations. Higher rock strength contributed to higher MDD, but the rock size didn't exhibit an obvious effect. It was also noticed MDD of the SRM was lower than that of the SRM under ideal condition. Additionally, it was observed that the deviation coefficient achieved the peak value when the rock content is 25%. Multivariate regression analysis revealed that the combination of clay content, rock size, rock strength and soil rock content accounted for more than 80% of MDD of the SRM, with mean absolute error of 0.037.

Keywords: Soil rock mixture, compaction characteristics, coarse grain interference crushing behavior

Introduction

(Poesen and Lavee, 1994)reported that soils rich in coarse fragments are common, usually observed in erosional and depositional landforms. It was also revealed that there is a big gap between the rock fragments and soil matrix in particle size and material composition. The soil particles are soft and hard, while the rock fragments are very rigid. The anisotropic behavior of soil rock mixture (SRM)and their deformation mechanism and are significantly affected by rock characteristics such as rock content (Rc), shape, porosity, gradation and distribution besides structural characteristics like composition, density and strength(Qian et al., 2020); (Gong et al., 2019). Laboratory test results also indicated that the most obvious influence on the compaction and mechanical properties of soil rock mixtures (SRM) prepared by the vibration compaction method is the soil–rock ratio, followed by the maximum particle size. Conversely, gradation did not exhibit any effect (Ji et al., 2021).

(Chai et al., 2014)highlighted that soil rock mixture (SRM) is composed of both coarse and fine particles with a certain gradation, and have better water permeability, higher strength and compactness than soil. Quantification of this material is important for soil and water management

(Khetdan et al., 2017).The presence of a layer of rock fragments will act as a root-restrictive layer to most crops that normally have a rooting depth of 60 cm such as corn and soybean).

The layer of large amounts of coarse fragments can also increase saturated hydraulic conductivity and macrospores', and reduce total porosity, water holding capacity, and subsequently available water content (Chow et al., 2007).

Besides the impact of gravel content in the soil matrix on root penetration, infiltration characteristics and soil moisture retention(Babalola et al., 1977);(Brakensiek and Rawls, 1994); (Ingelmo et al., 1994),it can also affect mechanical properties of soils(Rücknagel et al., 2013). The compaction and mechanical properties of SRM are complicated due to large difference in particle size and uneven gradation(Liu et al., 2019).

(Chinkulkijniwat et al., 2010) revealed that the compaction characteristics of gravelly soils are chiefly governed by the compactability of particles less than 4.75 mm, which is generally obstructed by the gravel interference. (Garga and Madureira, 1985)carried out a series of Proctor tests on gravelly soil in Brazil to investigate the impact of the compaction mold size and gravels on the compaction characteristics. They noticed that at about 20–25 % gravel, the interference of coarse grains begins to affect the compaction of the fine fraction. This obstruction reduces the compaction energy transmitted to the fine fraction.

(Setiawan and Technology, 2016)reported that empirical studies demonstrated that the percentage of the coarse fraction of the soil is affecting the soil both optimum water for compaction (OMC) and maximum dry density (MDD). The correlation analysis from this study showed a surge in MDD and a decrease in OMC with an increase in the content of coarse particles.

(SHAKOOR and COOK, 1990)exhibited that there was a steady increase in maximum dry density and a corresponding decrease in void ratio due to an increase in the stone content of a mixture of clay and aggregate up to 60-70%, irrespective of the shape and size of the added stone. The addition of crushed rock changes the mesostructure of the SRM material. Over the low range of rock content (0 – 30%) the rock content is low (0–30%), the contact force is mainly between the crushed rocks, and between crushed rocks and soil particles, but With the further increase of the rock content beyond this limit, the force chains formed between the crushed rocks tend to be perfect.

Unlike the above result, the findings of (Ji et al., 2021)showed that the maximum dry density initially increases and then decreases with the increasing the rock content and achieves the peak when the rock content is 60%. When the soil ratio in SRM is beyond this limit, the rock particles do not mutually contact with each other and are surrounded with soil particles, and a called suspended dense structure appears in SRM. (Garga and Madureira, 1985)illustrated that the compaction characteristics of gravelly soils are chiefly governed by the compactability of fine materials of 4.75 mm in diameter .This process is generally hindered by the gravel interference and at 20–25 % gravel content; the interference of coarse grains begins to affect the compaction of the fine fraction. On the other hand, (Winter et al., 1998) concluded that if the 20 mm gravels are greater than 45–50 %, these gravels determine the behavior of soil matrix.

So far, there have been only very few results on the effect of coarse fragments content on compaction behavior in the region under study and most of the globally obtained results does not match each other. Additionally, understanding of the impact of coarse particles on the compaction characteristic will be useful for various construction and agricultural purpose in the region under study. Accordingly, the current study was designed to target the following of objectives:

1) To describe the relationship between each of maximum dry density and optimum water content with the coarse fraction content of soil rock mixture.

2) To predict the maximum dry density of soil rock mixture from some selected coarse and fine fractions properties

3) To specify the effect the size and strength of coarse fraction on compaction characteristic of the soil rock mixture

4) To study the effect of coarse fraction interference on the compaction of the fine fraction.

5) To study crushing behavior of the coarse fragments

2. Materials and Methods

2.1. Collection of Materials

The base soils for this investigation were two fine grained soils obtained from two different locations with Sumail district, Duhok governorate. The first location is the experimental site of the College of agricultural engineering science, University of Duhok (36º 24′ 20″N and 44º 34′ 11″E), while the second location is Bacuz village (36º 55′ 49.63″N,43º 01′ 25.38″E), which is about 10 km from the center of Duhok city. Bulk soil sample was collected from the upper 0.5 m layer of the soil at each site. The sites were selected to obtain two dominant soils in the area under study with a wide range of clay content. Table 1. describes some selected physical and chemical properties of the two base soils.

Table1. Some selected physical, chemical and geotechnical properties of the soils used in compaction test.

Property		Unit	Average measured values	
			T1	T2
Particle size distribution	Clay	g kg^{1}	526	281
	Silt	g kg^{1}	400	545
	Sand	g kg^{1}	74	174
	Textural Name	-	Silty Clay	Silty Clay Loam
Soil bulk Density		Mg m^{-3}	1.37	1.151
PH		-	7.95	7.94
EC		dSm^{-1}	0.223	0.275
Organic Matter		g kg^{-1}	10.29	31.2
Calcium carbonate equivalent		g kg^{-1}	166.202	305.98

Indices Properties	LL	(%)	48.38	41.045
	PL	(%)	35.141	27.891
	PI	(%)	13.239	13.154

The additives of the soil rock mixtures were crushed stones from three limestone rocks , which were selected to cover a wide range of uniaxial compression strength. Representative crushed samples were from each type and screened to obtain two rock sizes (S1= 4.75 – 9.5 mm and S2= 9.5 – 20.0 mm). Table 2 shows some selected properties of the coarse fragment used during this investigation.

Table.2. some selected properties of the employed rock types in the compaction test.

Property	Unit	Average measured values		
		R1	R2	R3
Lithology	-	Limestone	Limestone	Limeston e
Uniaxial compressive strength	MPa	17.6	67.4	119
Dry density	Kgm^{-3}	2127	2681	2680
Water absorption	(%)	8.89	0.24	0.27

2. 2. Compaction Test

1. To perform the test, a representative sample of sufficient quantity was obtained for each soil by quartering method and air dried gradually. The air dry sample was passed through a 2.0 mm sieve and was then divided into portions of about 4.5 kg each.

3. For each treatment combination, the required amount of rock was mixed with base soil and its soil moisture content was raised to about 6%. The prepared specimen was set aside in tightly closed containers for a prescribed amount of soaking time of 16 hours for proper moisture conditioning.

4. This procedure was repeated over a range of soil water content unit then divided into five parts to be compacted in the mold in five approximately equal layers. Wet mass started to decrease indicating that the optimum water content was exceeded. Water was added incrementally to increase the individual moisture contents for each specimen by about 2%.

5. Before performing soil compaction, the assembly was placed on a hard surface. The assembly consisted of a cylindrical metal mould of internal diameter 150.4 mm, 127.3 mm height.

6. The first batch of soil was placed inside the mould with 56 blows of the modified hammer. The blows were uniformly distributed over the surface of the layer being compacted. To avoid stratification each compacted layer, the compacted surface was scratched with spatula before placing the next layer. Subsequently, the second batch of wet soil was placed and the same procedure was followed for all remaining four layers, each given 56 blows. The exact amount of

soil in each part was such that when compacted, all five parts will fill the mould (excluding the collar) to a point did not exceed ½ inches above the top.
7. The collar was removed and specimens was trimmed of the excess soil with a stainless steel straightedge to size in moulds
8. A balance with 1g readability was used to record the weight of the mould with the compacted soil and the base plate.
9. The Specimen was dismantled and a representative subsample of soil material was taken from the vertical central section of the test specimen for moisture content determination by gravimetric method.

10. The total unit weight (γ_t) was converted to dry unit (γ_d) via:

$$\rho_d = \frac{\rho_t}{1 + \frac{w}{100}} \qquad [1]$$

Where

ρ_d= dry soil unit weight (Mg m^{-3})

ρ_t= total unit weight (Mg m^{-3})

W = soil water content (%)

11. To study the rock crushing behaviour, the rock fragments of the rocks having medium strength were separated from the dismantled mixture by wet sieving.

12. Different values of moisture contents (w) and the resulting dry densities (DD), obtained after compaction were plotted both to arithmetic scale, the former as abscissa and the latter as ordinate. The points thus obtained are joined together as a curve. The moisture content corresponding to the peak of the curve is the optimum moisture for the compaction effort used in the test.

2.3. The crushing Behaviour of Coarse Fragments

The impact of rock characteristics(rock content, size and strength) was estimated on the crushing effect of compaction by comparing the gradation of the coarse fragments before and after compaction and the difference in gradation was assessed by calculating the deviation coefficient (S) from Equation [1] (Ji et al., 2021):

$$S = \sqrt{\frac{\sum_{i=1}^{n} \left(Pbi - pfi\right)^2}{n-1}} \qquad [2]$$

Where:

Pbi = Percent passing the sieve i before compaction
Pfi = Percent passing the sieve i after compaction
N = number of sieves.

2.4. The impact of Rock Fragments Characteristics on the Compactability of the Fine Materials.

The maximum dry density of the materials < 4.75 mm was obtained from

$$\rho_s = \frac{P_s\ \rho_m}{1 - \frac{P_r \rho_m}{\rho_r}} \quad [3]$$

Where:
ρ_s = the dry density of the soil (< 4.75mm)
ρ_r = the average density of the rock fragments
ρ_m = the dry density of the soil rock mixture
P_s =proportion of the fine fraction
P_r =proportion of the rock fragments
Wet oxidation method according to Walkley-Black method (Allison and properties, 1965).

2.5. The maximum dry density (MDD) of the SRM under Ideal condition

The MDD of the SRM, where there is no interference from coarse materials ($\rho_{m,I}$) was calculated according to (Chinkulkijniwat et al., 2010):

$$\rho_{m,I} = \frac{1}{\frac{P_s}{\rho_{s,f}} + \frac{P_r}{\rho_r}} \quad [4]$$

2.6. Soil Analysis

Particle size distribution was determined by using both hydrometer and sieving methods according to the procedures described by (Klute and methods, 1986).The soil bulk density was measured by core method as outlined by (Blake et al., 1986).The Atterberg's determined limits (LL and PL) were as per the ASTM D4318 Standard. The liquid limit was determined using the standard liquid limit device (Casa grande apparatus) and multipoint test method. The plastic limit was determined on the same portion of the prepared soil paste. The rock uniaxial compression strength was measured by using unconfined compression test after preparing rock samples for this test. The water absorption for rocks was measured by soaking representative samples in water at room temperature 20 ± 4 hrs. The dry density for rocks was measured by rock submergence using a wire mesh basket. The soil organic carbon was measured by wet oxidation method according to Walkley-Black method (Allison and properties, 1965).The pH of the saturation extract was measured with pH-meter Model Hanna pH211 according to Jackson (1958). The electrical conductivity of the saturation extract (EC_e) was measured with EC-meter Model and adjusted to 25 ºC according to (Hesse, 1972)

2.7. Methods of Data Analysis

The data were subjected to different statistical analysis. Pearson's correlation matrix was established using IBM SPSS software ver. 22. Linear and non-linear least squares techniques have been used to determine the parameters of the proposed models in the present study using Microsoft Excel Spread sheet and IBM SPSS software ver. 22. Following models derivation, the Shapiro-Wilk test was used to examine the normality of the residuals. Statgraphics software Release plus 4 was employed to detect multicoinearity among the regressors of proposed models. Durban – Watson test was used to detect autocorrelation or serial correlation.

3. Results and Discussion

3.1. Description of Compaction Characteristics Database

The obtained data presented in Table 3 exhibit summary information about the central tendency, the dispersion (variability) and distribution of each of maximum dry density (MDD) and optimum moisture content (OMC).

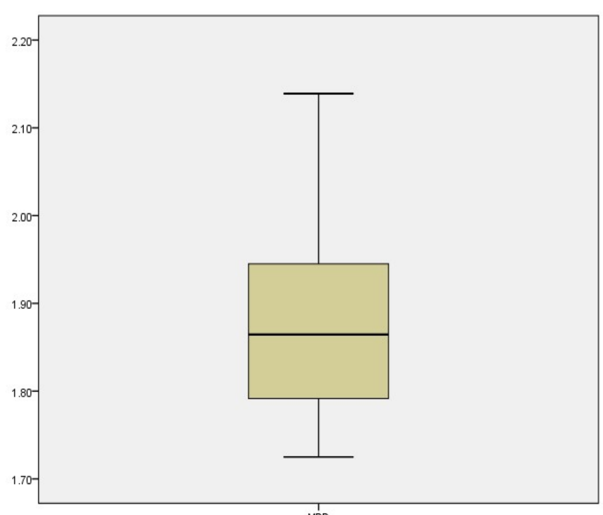
It can be observed from Table.3 that the optimum soil moisture for compaction varied from a minimum of 8.1% under treatment combination T2S1R3L6 to a maximum of 18.31% for the Sumail soil without rocks. It can also be elucidated from Table 3 that maximum dry density (MDD) ranges from as low as 1.73 $gcm^{-3}$for Sumail soil without rock to as high as under treatment combination T2S2R2L6. It is interesting to note that with no exception that the compaction curves from which these data were extracted, were bell shaped ones without any departure. No curve in form of one and one-half peak, double peaked and odd shaped type were obtained. It is also obvious from Table 3 that the MDD was positively skewed (skewed to the right) Unlike MDD, the OMC was negatively skewed (skewed to the left). The obtained skewness was within the range of -1 to +1. This indicates that the database was considered as normally distributed data (Di Virgilio et al., 2007);(Paz-Gonzalez et al., 2000).

Additionally, the Kolmogorov –Smirnov and Shapiro-Wilk statistics confirmed the normal distribution of OMC only. The box plots shown in Fig. 1 revealed that the OMC resulted in a longer box with medium line at the centre and with nearly equal whisker lengths indicating that its data is highly dispersed and normally distributed. Conversely, the box plot for MDD points to slight deviation from normality and less dispersed compared with OWC. The Whisker of MDD is shorter on the upper end of the box, reflecting that the distribution is positively skewed.

Table 3. Summary of descriptive statistics for MDD and OWC of the soil rock mixtures used during this study.

Indices			Statistic	Std. Error
MDD	Mean		1.8827	0.01283
		Lower Bound	1.8571	

	95% Confidence Interval for Mean Upper Bound	1.9083	
	Median	1.8645	
	Variance	0.012	
	Std. Deviation	0.10890	
	Minimum	1.73	
	Maximum	2.14	
	Range	0.41	
	Interquartile Range	0.16	
	Skewness	0.781	0.283
	Kurtosis	-0.342	0.559
OWC	Mean	14.7314	0.38284
	95% Confidence Interval for Mean Lower Bound	13.9680	
	95% Confidence Interval for Mean Upper Bound	15.4947	
	Median	14.9400	
	Variance	10.553	
	Std. Deviation	3.24854	
	Minimum	8.10	
	Maximum	18.31	
	Range	13.71	
	Interquartile Range	4.89	
	Skewness	-0.271	0.283
	Kurtosis	-0.588	0.559



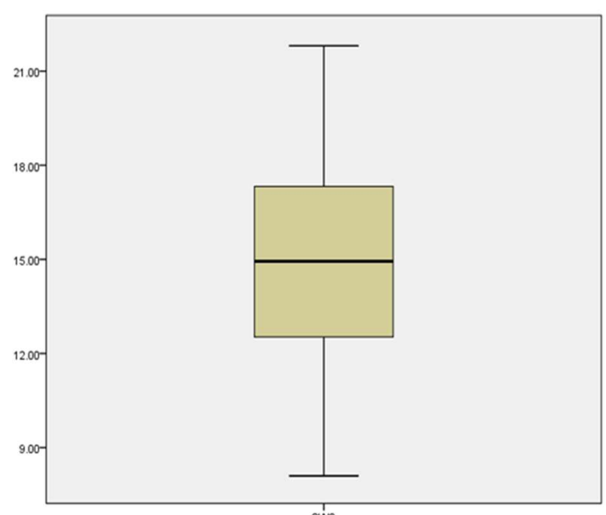


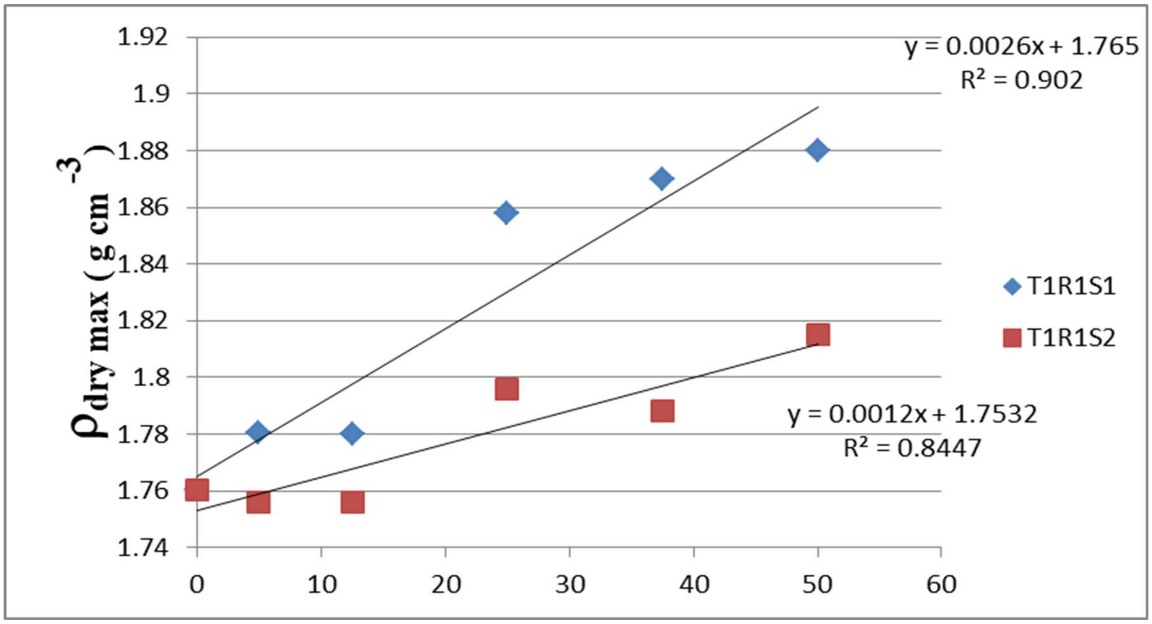
Figure1. Box-Whisker plot for both MDD and OWC

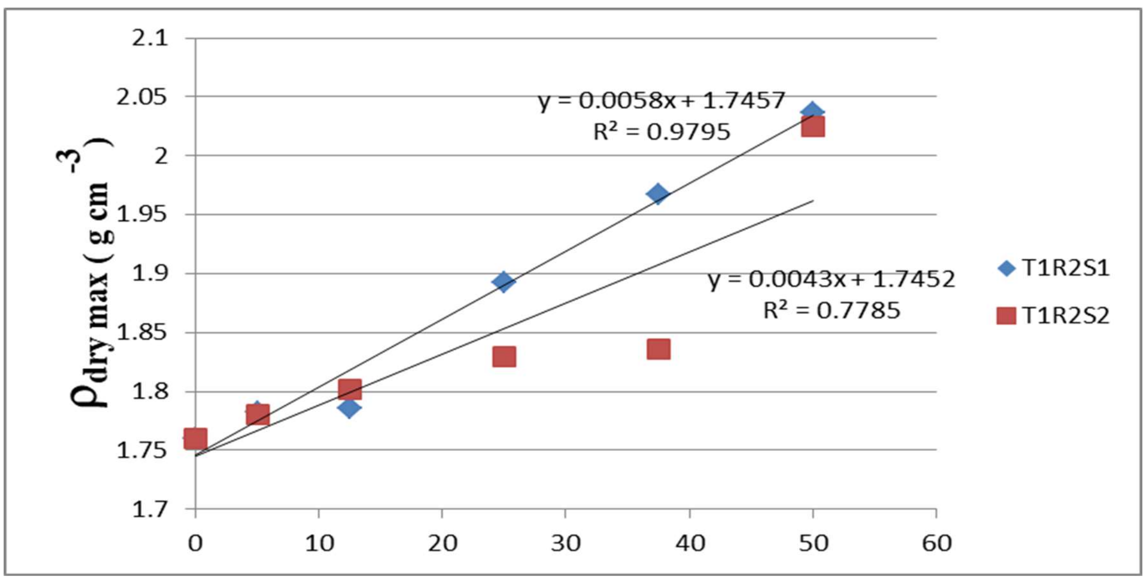
Figure 1 Alt Text. The figure to the left is the box-whisker plot for optimum water content (OWC). The figure to the right represents box-whisker plot for maximum dry density (MDD). The centre line in each figure represents the median of each set and the upper and lower cap represents the upper and lower extremes. The lower base of each box represents first quartile, while the upper base represents the third quartile. Departure of the median line from the centre of the box indicates deviation from normality distribution of the data.

3.2. Variation of MDD with different soil rock content

Figs. 2 and 3 illustrate the variation of the MDD of the soil rock mixtures with various rock contents. It can be seen that the MDD increases linearly with an increase in soil rock content under most of the treatment combinations. Since the density of rock fragments is greater than that of the base soils, it is expected that, higher soil rock content will be responsible for the higher maximum dry density of the soil rock mixtures. It can also be noticed that the amount of increase is not uniform over the entire range of the soil rock content. (Ma et al., 2021)have assigned the non-uniformity in the amount of increase in MDD to the fact that the rock fragments will be encased in the clay and the will be not contact among the fragments when the soil rock content is low (< 45%). when the rock block content is greater than 60%, a high proportion of the rock begin to contact completely. Overall, the MDD for the rock size of (S2=9.5 -19 mm) was superior to those of the smaller size (S1= 4.75 – 9.5 mm). Additionally, it is evident that at a given soil rock content, the MDD tended to increase with increase in rock strength. Since the density of rock fragment with a higher strength has relatively greater than that of rocks with a lower strength, higher rock strength will contribute to the higher maximum dry density of the soil rock mixture.

Unlike the MDD, the optimum soil moisture content (OMC) tended to decrease with an increase in soil rock content over its entire range. It is commendable to mention the details of this parameter are not given through this article and the focus was on MDD.


y = 0.0026x + 1.765
R² = 0.902
y = 0.0012x + 1.7532
R² = 0.8447
ρdry max (g cm -3)
T1R1S1
T1R1S2


y = 0.0058x + 1.7457
R² = 0.9795
y = 0.0043x + 1.7452
R² = 0.7785
ρdry max (g cm -3)
T1R2S1
T1R2S2

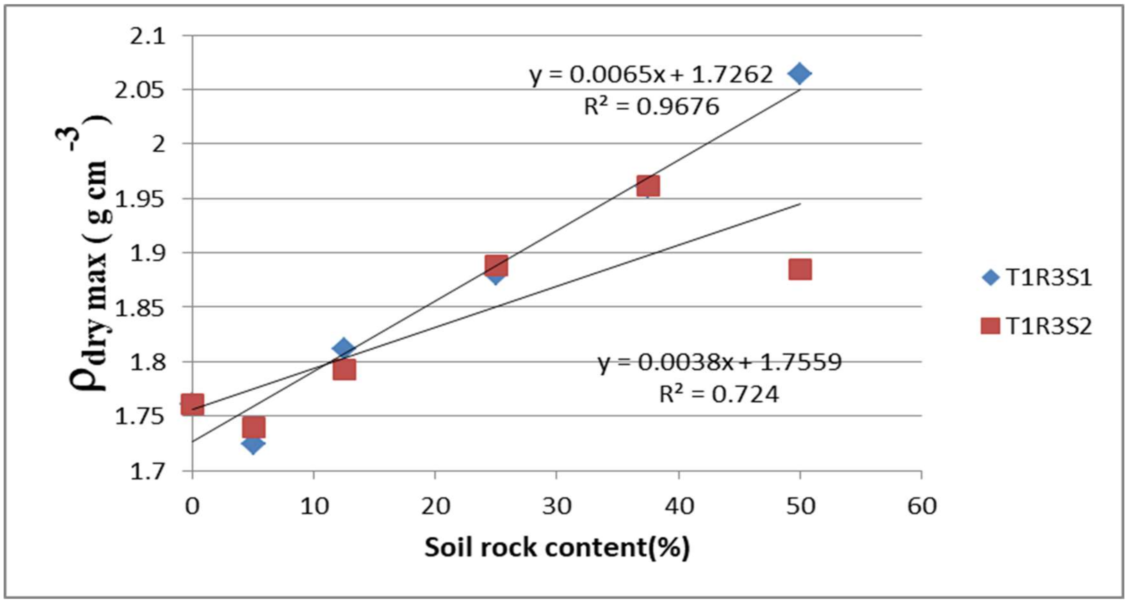
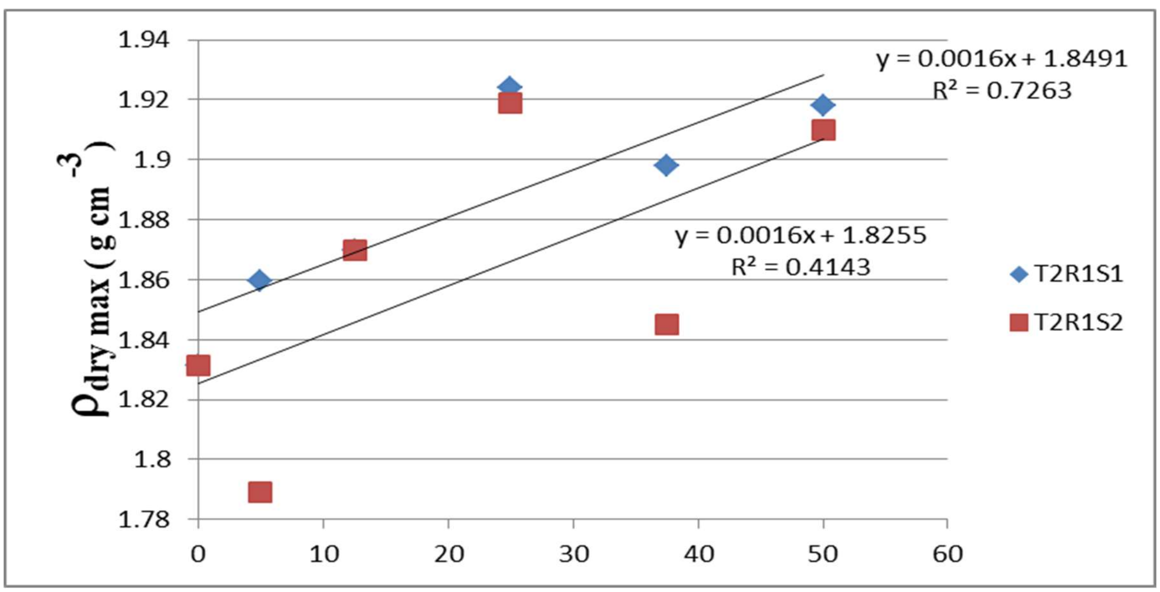
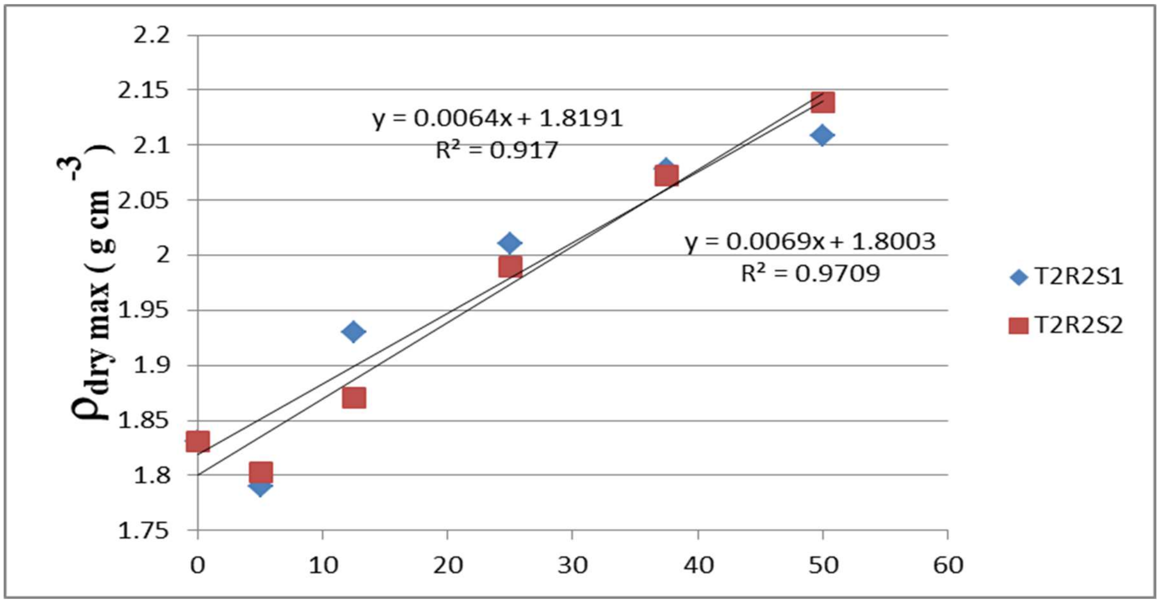


Figure 2. Maximum dry density as affected by rock content of the Sumail soil under different treatment combinations during modified compaction test.

Figure 2 Alt Texts. Blue diamond stands for the first rock size (S1= 4.75-9.5 mm). Red square is for the second rock size (S2 = 9.5-20 mm). T1 means the Sumail base soil (clay content=52.6%). Plot A is for rock strength of (R1=17.6 kPa); Plot B is for rock strength of (R2=67.4 kPa) and Plot C is for rock strength of (R3=119 kPa).





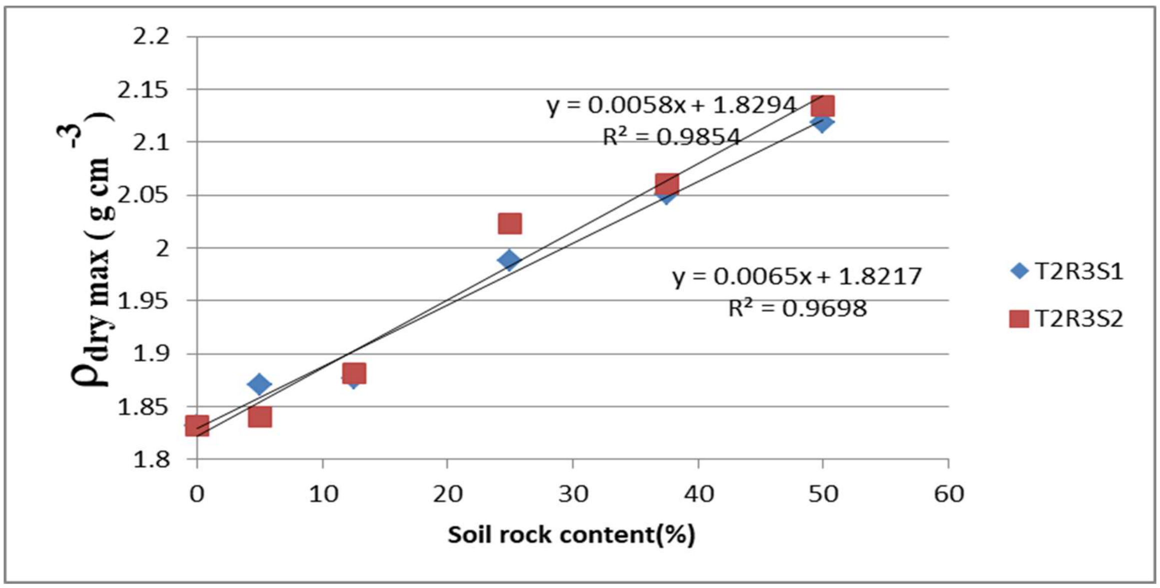
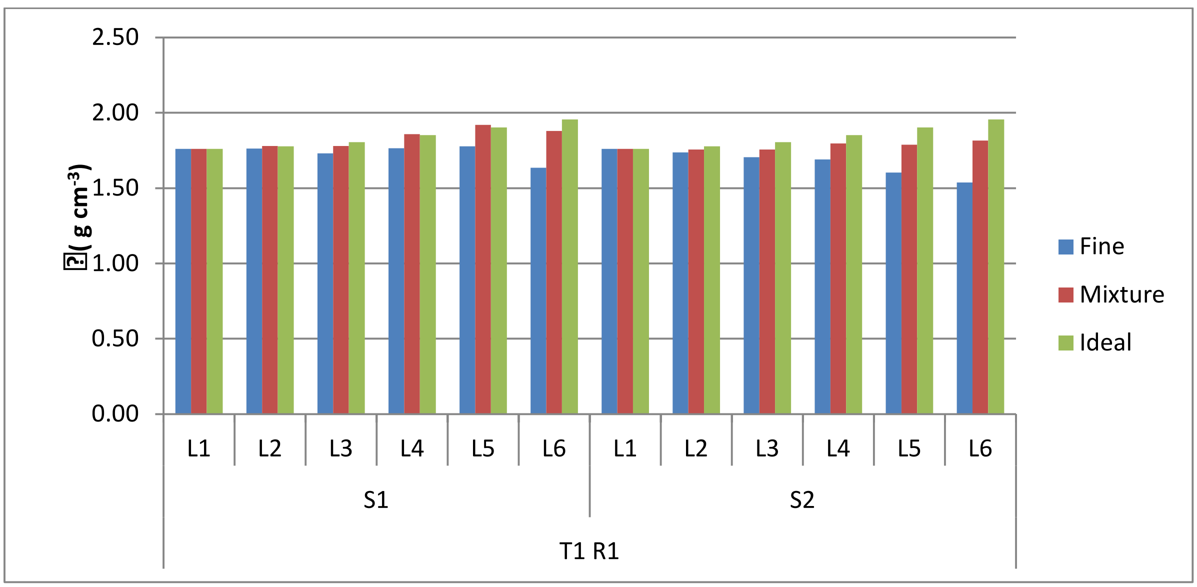


Figure3. Maximum dry density as affected by rock content of the Bacuz soil under different treatment combinations during modified compaction test

Figure 3 Alt Texts. Blue diamond stands for the first rock size (S1=4.75-9.5 mm). Red square is for the second rock size (S2 =9.5-20 mm). T2 means the Bacuz base soil with (clay content 28.1%). Plot A is for rock strength of (R1=17.6 kPa); Plot B is for rock strength of (R2=67.4 kPa) and Plot C is for rock strength of (R3=119 kPa).

3.3. Rock Fragments Interference during compaction of Soil Rock Mixture.

The results portrayed in Figs.4 and 5 compare the maximum dry densities of the base soils and soil rock mixture and those for the soil rock mixtures under ideal condition (ρ_s, ρ_m and $\rho_{m,I}$). The plotted results indicate that the rock interference starts upon addition of rock fragments, i.e., at the L2 onwards. This implies that the maximum dry density of the base soils were lower that of the soil rock mixture irrespective of level of soil rock content. This interference diminishes the energy transmitted to the fine material. Unlike these results, (Chinkulkijniwat et al., 2010) have used standard Proctor compaction test under various soil gravel proportions and noticed that the gravel interference effect starts at about 20 % gravel and is irrespective of gravel size. The obtained results also disagree with (Garga and Madureira, 1985) works .The departure of the maximum dry density of the pure soils tended to increase with an increase in soil rock content. Overall, the effect of rock size on this phenomenon is not evident. On the other hand, there is indication of an increase in deviation with a decrease in rock strength.
It is also evident from the displayed results that interference between the maximum dry density of the soil rock mixture (ρm) and that under ideal condition ($\rho_{m,I}$) for the two base soils started at the second level of soil rock content (L2=5%) . Like the deviation between ρ_s, ρ_m the deviation between and ρ_m $\rho_{m,I}$ tended to increase with an increase in the soil rock content.



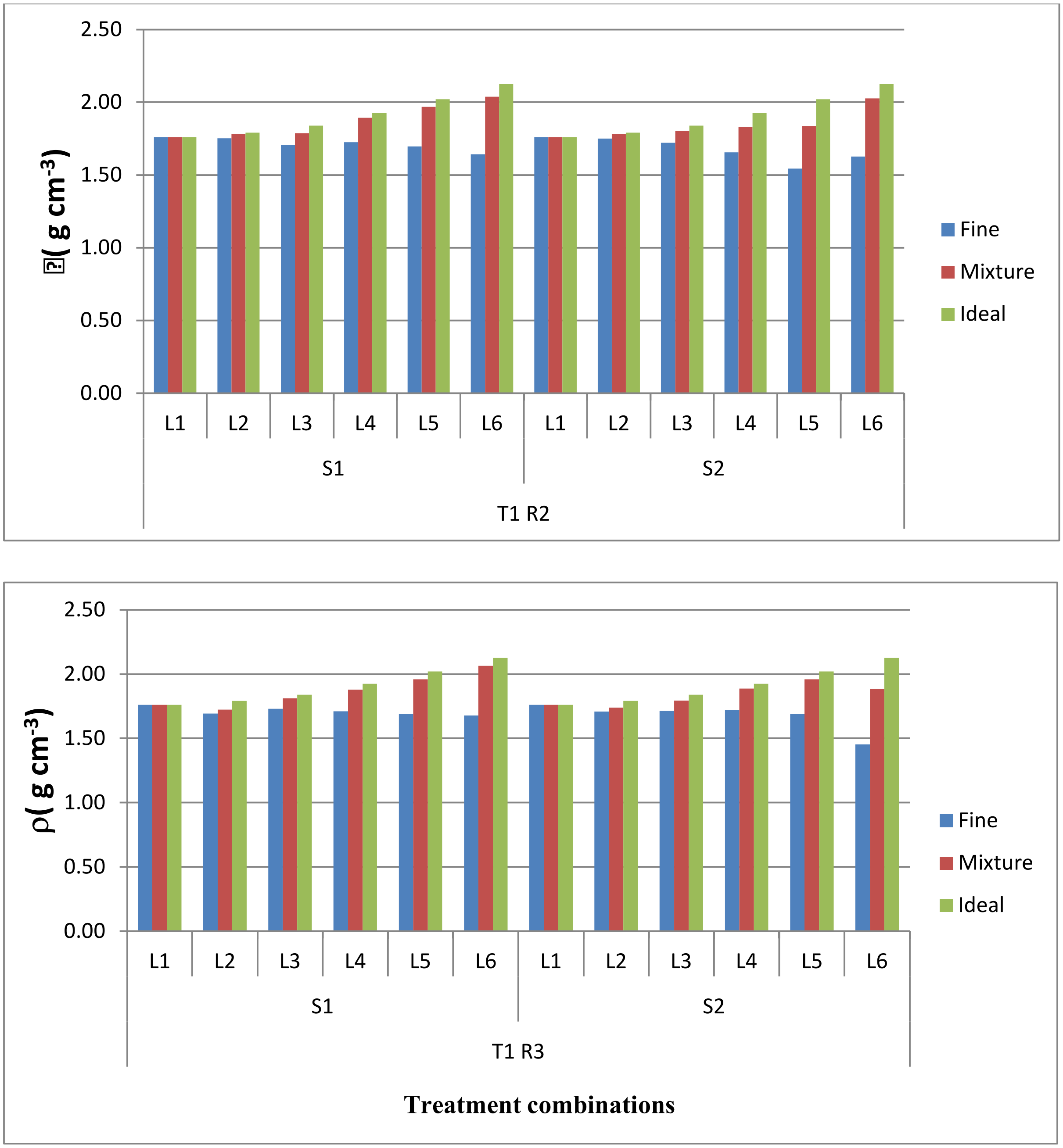
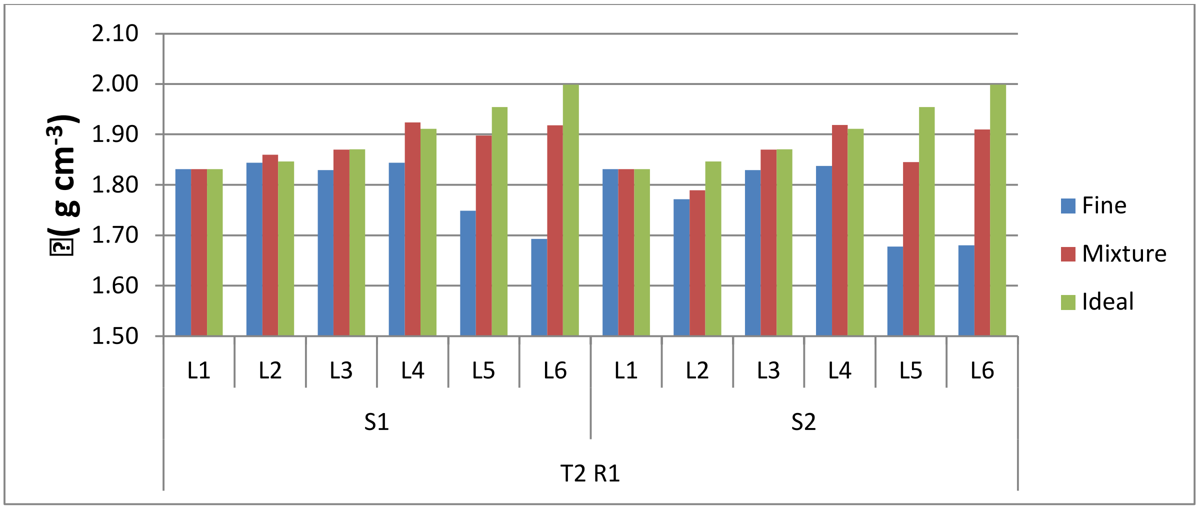
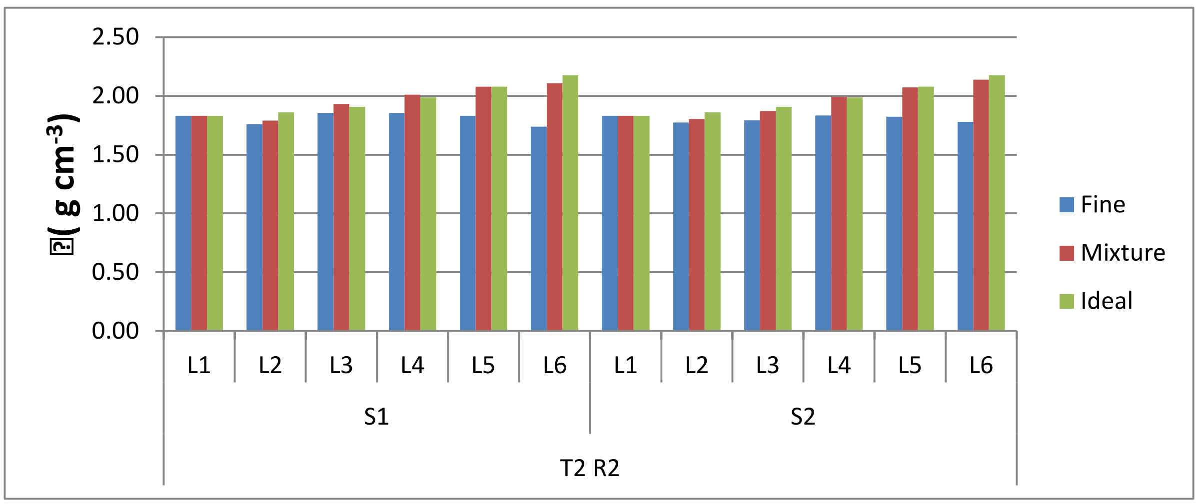


Figure 4. Comparison of the maximum dry densities of Sumail base soil, soil rock mixture and soil rock mixtures under ideal condition.

Figure 4 Alt Texts. The blue, red and green bars are representing the MMD (maximum dry density) of base soil, soil rock mixture and under ideal condition; the first rock size (S1= 4.75-9.5 mm) and second rock size (S2 =9.5-20 mm). Figs. a, b and c are specific for Sumail base soils with clay content=52.6%, rocks of different compressive strength (R1=17.6, R2=67.4 and R3=119kPa respectively); and the rock content (L1=0%,L2=5%,L3=12.5%,L4=25%,L5=37.5%, and L6=50%).


(g cm-3)
2.10
2.00
1.90
1.80
1.70
1.60
1.50
L1
L2
L3
L4
L5
L6
S1
S2
T2 R1
Fine
Mixture
Ideal


(g cm-3)
2.50
2.00
1.50
1.00
0.50
0.00
L1
L2
L3
L4
L5
L6
S1
S2
T2 R2
Fine
Mixture
Ideal

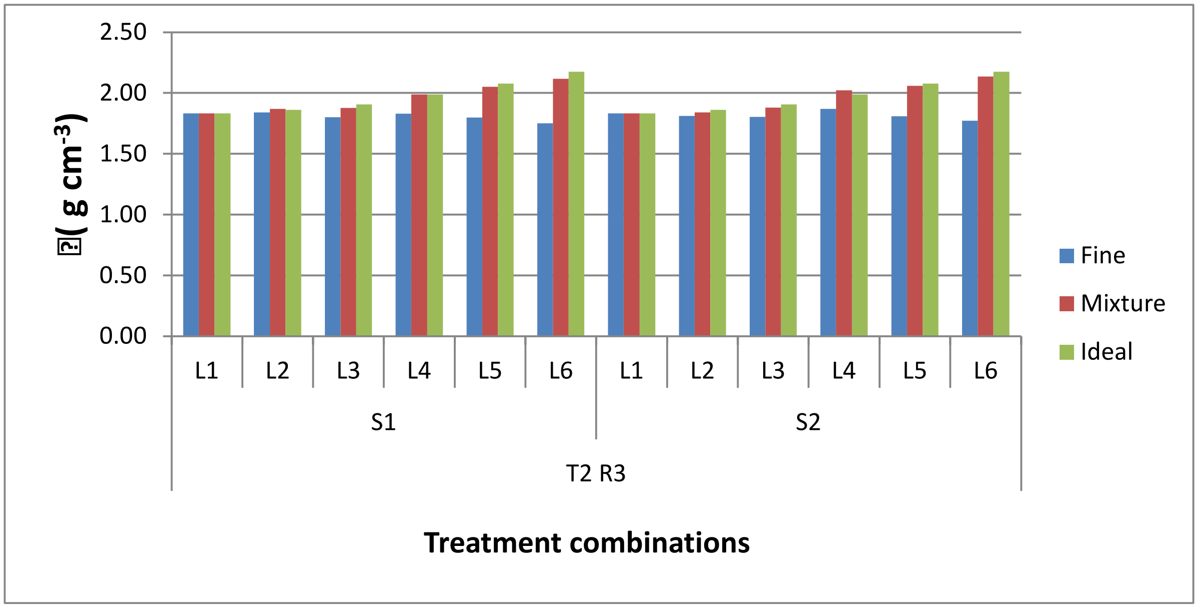


Figure 5. The maximum dry density of soil rock mixture under different treatment combination in Bacuz soil.

Figure 5 Alt Texts. The blue, red and green bars are representing the MMD (maximum dry density) of base soil, soil rock mixture and under ideal condition; the first rock size (S1= 4.75-9.5 mm) and second rock size (S2 =9.5-20 mm). Figs. a, b and c are specific for Bacuz base soils with clay content=28.1%, rocks of different compressive strength (R1=17.6, R2=67.4 and R3=119kPa respectively); and the rock content (L1=0%,L2=5%,L3=12.5%,L4=25%,L5=37.5%, and L6=50%).

3.4. Effect of Different Treatment Combinations on gradation variation of the Soil Rock Mixture

To investigate the impact of the different treatment combinations on the gradation variation of the coarse fragments of the soil rock mixtures, their gradation were compared before and after compaction via the deviation coefficient (S). This coefficient was calculated according to equation (2) and the results are presented in Table 4. The deviation coefficient ranged from as low as 6.89 mm under T1S1R2L4 to as high as 30.47 mm under T1S2R1L2 and the remaining values fell between these two extremes. The larger the S has a more significant crushing effect on the SRM coarse particles (Ji et al., 2021).

As can be seen from Table (4), there is no a steady decrease in the crushing effect of the modified compaction with an increase in rock content of the soil rock mixture under the study treatments. The deviation coefficient initially decreased and then increased with the increasing the rock content and achieved the peak when the rock content is 25%. This may be due to the spatial structure of the soil rock mixture (Ji et al., 2021).This result disagree with finding of (Wang et al., 2009),who studied the effect of coarse-grain (grain size > 5 mm) contents on the crushing behaviour of weathered phylite, concluding that the particle crushing first increases and then decreases with increments of rock fragments. Conversely this finding is in concordance with findings of (Liu et al., 2019),who conducted compaction on a weathered phyllite fills with rock contents of 35%, 45%, 55%, 65% and 75% (by weight). They revealed that 55% rock content exhibited the least breakage and were most suitable for filling the subgrade.

It is also evident from the presented data that at the same level of soil rock content the crushing effect tends to decrease with an increase in rock strength. This may attribute to the fact that the fragments are prone to becoming crushed to smaller particles as the bonding strength decreases. Furthermore, there is no an obvious influence of rock size on size on the value parameter. This investigation will provide an experimental basis and reference for the selection and use of backfill materials in urban subsidence areas (Cai et al., 2020).

Table4. Effect of different treatment combinations on the deviation coefficient of the rock fragments

Rock strength (MPa)	Soil rock content (%)	Deviation coefficient (S)for rock size	
		4.75- 9.5 mm	9.5 - 19.0 mm
17.6	5	30.23	30.47
	12.5	23.65	21.20
	25	21.41	16.59
	37.5	21.97	19.57
	50	25.52	23.95
67.4	5	22.11	21.53
	12.5	11.32	10.50
	25	6.89	7.89
	37.5	7.00	8.21
	50	8.21	11.45
119	5	18.93	24.53
	12.5	10.72	12.93
	25	7.94	8.83
	37.5	11.19	13.24
	50	13.45	17.84

3. 5. Prediction of Compaction Characteristics

3.5.1. Correlation Matrix for Interrelationship among the input Variables

Table 5 presents bivariate correlation analysis results or the correlation matrix for the input variables with a sample size of 72 treatment combinations. The regressors encompassed clay content, rock size, rock strength and rock content of the soil rock mixtures. As can be noticed in Table 5, the interrelation between the MDD and rock size offered the weakest correlation

coefficients (r= -0.102). On the contrary, the soil rock content offered the highest correlation with MDD (r =0.730), which was significant at (P≤ 0.01) followed by clay content (r=- 0.427).
It is commendable to mention the intercorrelation between the input variable were displayed as a guide to avoid multicollinearity problem during model calibration. From the correlation matrix shown in Table 5, it can be concluded that the variance inflation factor (VIF) is less than 10 and the tolerance ((T) is more than 0.1 for each of the regressor, it means that the proposed model has not the problem of multicollinearity.
Unlike to MDD, each of soil rock content and rock strength were negatively correlated with OMC, while each of clay content and rock size were positively with OMC. It is interesting to note that the soil rock content exhibited the strongest correlation coefficient with OMC(r= -0.780) which was significant at (P ≤ 0.01).
Table 5. Correlation matrix showing the relationship among some selected input and the maximum dry density of the rock mixtures.

Variable	Variable				
	Clay content	Rock size	Rock strength	Soil rock content	Maximum dry density
Clay content	1	0.000	0.000	0.000	-0.427**
Rock size		1	0.000	0.000	-0.102
Rock strength			1	0.000	0.254*
Soil rock content				1	-0.730**
Maximum dry density					1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

3.5.2. The interrelation between Maximum Dry Density and Optimum Moisture Content for Compaction

Additionally, another attempt was made to predict OMC from MDD (Fig.6) The power function model offered the highest performance in term of R^2. More than 71% of variation in OMC is attributed to variation in MDD. There is relatively a wide data scattering over the intermediate range of range of OMC. The results indicated that the mean absolute error of prediction of OMC is about 1%. It is interesting to note that no further improvement was obtained upon log transformation of OMC. In contrast, (GURTUG et al., 2015) obtained more accurate results upon log transforming the values of OMC.

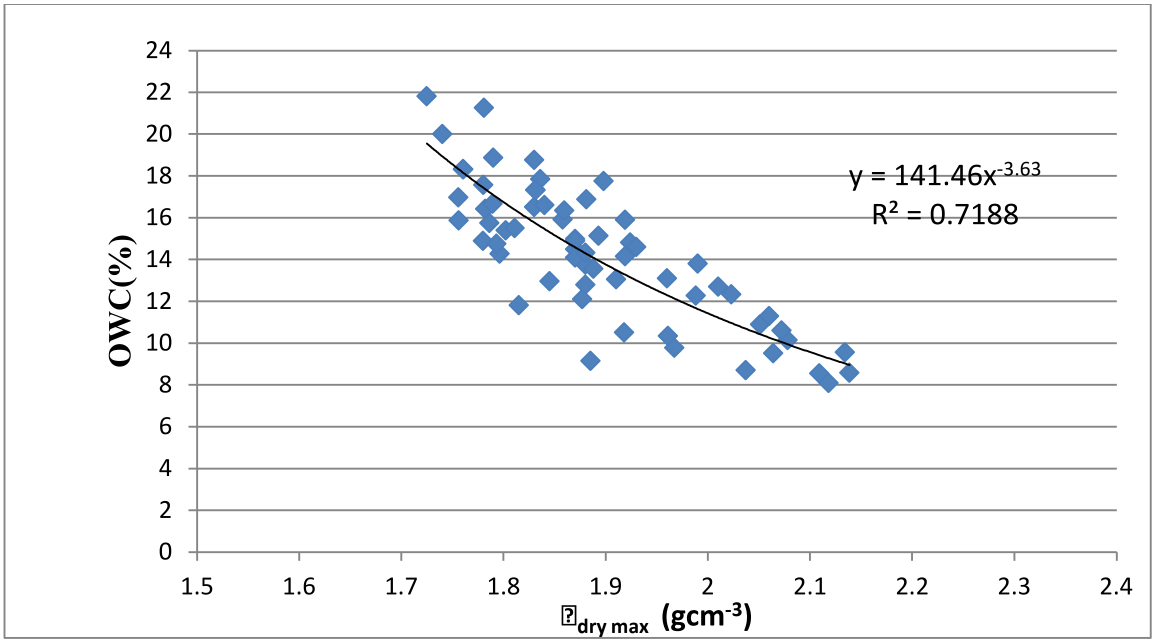


Fig.6. Relationship between maximum dry density and the optimum water content of the soil rock mixtures.

Figure 6 Alt Texts. The blue diamond's represent the data points. Each point represents a certain treatment combination of soil type, rock size, soil rock content and rock strength. The plotted curve is representing a power function model relating optimum water content and maximum dry density (OWC to MDD).

3.5.3. Prediction of MDD from the Study Input Variables

The stepwise algorithm was followed to specify which predictor variables were to be included in the regression equations. It is noteworthy to mention that adding all the remaining variables to the proposed models gave rise to significant improvement of prediction of ρ_m, they did not create the problem of multicollinearity. According to our findings, all the study input variables have emerged to be effective properties for predicting ρ_m. Table 6 displays the coefficients of the input variables for the proposed multivariate model for predicting the MDD of the soil rock mixtures (ρ_m). This variable accounted for 53% of variation in ρ_m.

Table.6. Regression coefficients for the relation between maximum dry density and each of some selected soil and rock characteristics along with several efficiency criteria for the proposed model

Model classification	$\rho_{dry\ max} = \beta_o + \beta_1$ Clay+β_2 Rock ize+β_3 Rock strength + β_4 Soil rock content					Performance Indicators								
	βo	β1	β2	β3	β4	R^2	R^2_{adj}	MBE	MAE	MAPE	CRM	RMSE	CV

Multivariate linear regression model	1.8879	-0.0030	-0.0023	0.00067	0.0046	0.81	0.80	0.00	0.037	1.98 %	0.00	0.047	2.518%

To further confirm the results, a host of performance indicators pertinent with the proposed Model were calculated and depicted Table 6. It is also obvious from Table. 6 that the combination of the suggested predictors explained more than 80% in ρ_m of the soil rock mixtures. The mean absolute error and mean absolute error percentage of prediction of ρ_m were 0.037 and 1.98% respectively, indicating that ρ_m can be predicted with a reasonable degree of accuracy. Judging from MAPE, the proposed model fell within the forecast potentially good (Koffman and Lewis, 1997).Smaller RMSE, MAE and MAPE values from a given approach indicate the closeness of the modelled values to the observed ones. The mean absolute percentage error (MAPE) is one of the most widely used measures of forecast accuracy, due to its advantages of scale-independency and interpretability. However, MAPE has the significant disadvantage that it produces infinite or undefined values for zero or close-to-zero actual values (Kim and Kim, 2016) Based on the classification scheme proposed by (Wilding, 1985) the coefficient of variability of the predicted and observed ρ_m values is low (CV <15%). Judging from Values of mean biased error (MBE) and coefficient of residual mass (CRM), the proposed model neither under predicted nor over predicted the MDD of the soil rock mixture.

To investigate the degree of agreement between the observed and predicted values , the predicted values of the MDD from the proposed model were plotted versus the observed values of in relation to line 1:1. As can be seen from Fig. 7 that the majority of the plotted points falls on or close to the line 1:1. It can also be noticed from Fig.7 that the slope of the regression line is close to unity and the intercept is close to zero.

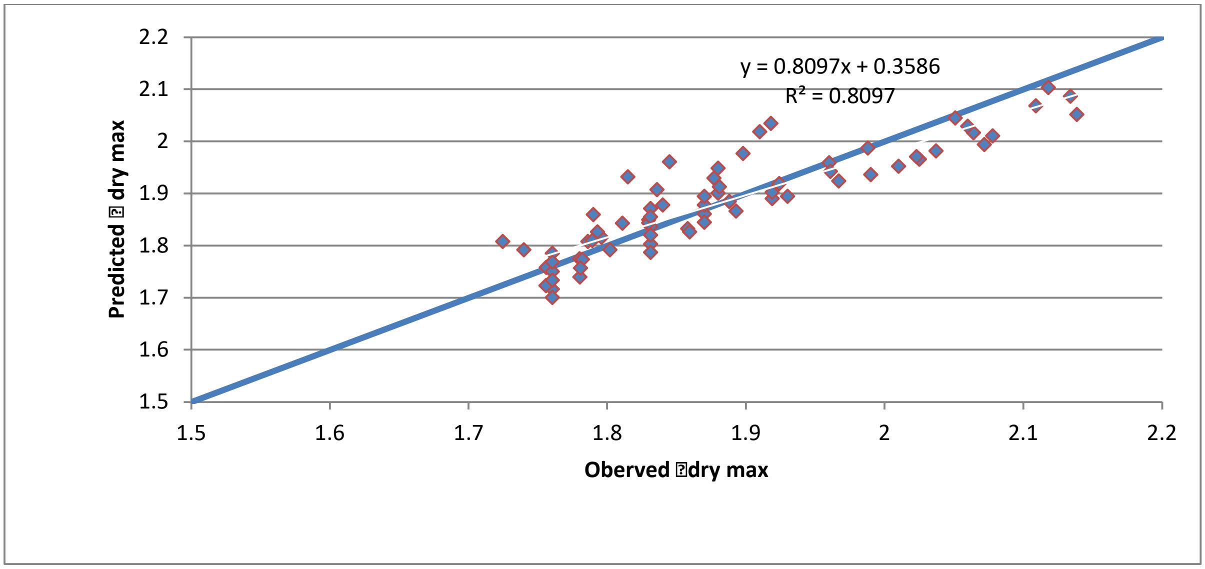


Figure7. Plot of predicted maximum dry density values versus observed values in relations to line 1:1.

Figure 7 Alt Texts. The observed values represent the measured values of the maximum dry density (MDD) in the laboratory. The predicted values are the values of MDD obtained from the multi-regression model. The straight line is a line drawn with angle of 45° to show the degree of match between the observed and predicted values.

Additionally, the Kolmogorov –Smirnov and Shapiro-Wilk statistics revealed the residuals of predicted MDD are normally distributed. The plot of residual versus the observed values for the MDD further confirms the normality of these data (Table.7).

Table 7. Test of normality for MDD and OWC using robust statistical methods

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
OWC	0.079	72	0.200*	0.971	72	0.090
MDD	0.120	72	0.013	0.919	72	0.000

4. Conclusions

There is a steady increase in the MDD of SRM with an increase in soil rock content over the range of soil rock content between 5% and 50% and the least breakage occurred at 25%. Further, it can be concluded that the interference occurs at all level of soil rock content and the departure of MDD of the pure soil increases with an increase in soil rock content. Additionally, it is possible to predict the maximum dry density of the soil rock mixture with a reasonable accuracy from the study input variables. This will provide reference for the selection and use of backfill materials in urban subsidence areas.

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