Performance of Granular Volcanic Ash-Cement-Fine Soil Mixture for Sub-Base Coarse of Road Pavement in Yemen

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Abstract:

Granular Volcanic Ash (GVA) is a material of volcanic activity characterized by a rough surface, low specific gravity, non-plasticity particles with poor gradation, and high porosity because of its mineral structure. This study aimed to evaluate the performance of GVA-cement-fine soil mixtures as a sub-base material for flexible pavement in Yemen. GVA was blended with fine soil at 0%, 10%, 20%, and 30% by dry weight of GVA to improve gradation and reduce the required cement. The mixtures were stabilized with 2%, 5%, and 8% cement by dry weight of GVA. Performance was assessed through compaction characteristics, unconfined compressive strength (UCS), indirect tensile strength (ITS), wetting–drying durability, and ultrasonic pulse velocity (UPV) on samples cured for 7 and 28 days. The results revealed that the applied compaction energy reduced the fineness modules of the coarse GVA by 23%. Increases in cement content and curing time produced higher UCS, ITS, and UPV values. The GVA-cement-fine soil mixture met the strength and durability requirements for a sub-base for medium-traffic roads when GVA contained 20% fine soil and was stabilized with 5% cement.

Keywords: Granular Volcanic Ash, Yemen, soil stabilization, unconfined compressive strength, indirect tensile strength, wetting–drying durability test, ultrasonic pulse velocity.

أداء خليط الرماد البركاني الحبيبي والأسمنت والتربة الناعمة المستخدم كطبقة تحت الأساس لرصف الطرق في اليمن

الملخص:

تعتبر مواد الرماد البركاني الحبيبي من المواد الناتجة عن النشاط البركاني؛ تتميز هذه المواد بسطح خشن، ووزن نوعي منخفض، وحبيبات غير لدنة وذات تدرج ضعيف، ومسامية عالية ويرجع ذلك الى تركيب المعادن المكونة لها. الغرض من هذه الدراسة تقييم أداء خليط الرماد البركاني الحبيبي والأسمنت والتربة الناعمة المستخدمة كطبقة تحت الأساس في الرصف المرن في الجمهورية اليمنية. تم خلط مواد الرماد البركاني الحبيبي مع تربة ناعمة بنسبة مختلفة (0%، 10%، 20%، و30% من الوزن الجاف من الرماد البركاني الحبيبي) وذلك لتحسين تدرج الرماد البركاني الحبيبي، وأيضا لتقليل كمية الأسمنت المطلوبة لتثبيت هذا الخليط وذلك بمحتوى أسمنت مختلف (2%، 5%، و8% من الوزن الجاف للرماد البركاني الحبيبي). تم تقييم أداء الخليط من خلال معيار الدمك، ومعيار المقاومة، ومعيار المتانة، ومعيار سرعة انتقال الموجات فوق الصوتية في الخليط وذلك بعد فترة معالجة 7 و28 يومًا. وفقًا لنتائج الاختبارات المعملية، والتي شملت: اختبار الدمك المعدل، واختبار الضغط غير المحصور، والشد غير المباشر، واختبار المتانة لدورات الترطيب والتجفيف، واختبار سرعة انتقال الموجات فوق الصوتية، تبين أن طاقة الدمك المستخدمة سببت نقصان في معيار النعومة لحبيبات الرماد البركاني بنسبة 23%. كما أظهرت النتائج أن زيادة محتوى الأسمنت، وطول فترة المعالجة لعينات الخليط سببت زيادة في قيم المقاومة للضغط غير المحصور والمقاومة للشد غير المباشر وفي سرعة انتقال الموجات فوق الصوتية. من ناحية أخرى، يحقق خليط الرماد البركاني الحبيبي والتربة الناعمة والاسمنت متطلبات المقاومة والمتانة للتربة المستخدمة كطبقة تحت الاساس للطرق متوسطة الحركة عند خلط مواد الرماد البركاني الحبيبي 20% تربة ناعمة وتثبيته بـ5% أسمنت.

الكلمات المفتاحية: الرماد البركاني الحبيبي، اليمن، تثبيت التربة، مقاومة الضغط غير المحصور، مقاومة الشد غير المباشر، اختبار المتانة (الترطيب والتجفيف)، سرعة انتقال الموجات فوق الصوتية.

1. Introduction

Granular volcanic ash (GVA) materials are a widely available in many parts of Republic of Yemen [1]. It spread above surface area estimated by 17000 km2 from the total area of Yemen as shown in Figure 1 [2]. The estimated reserve of Granular volcanic ash (GVA) in Sana'a volcanic field is about 411 million m3 [3].

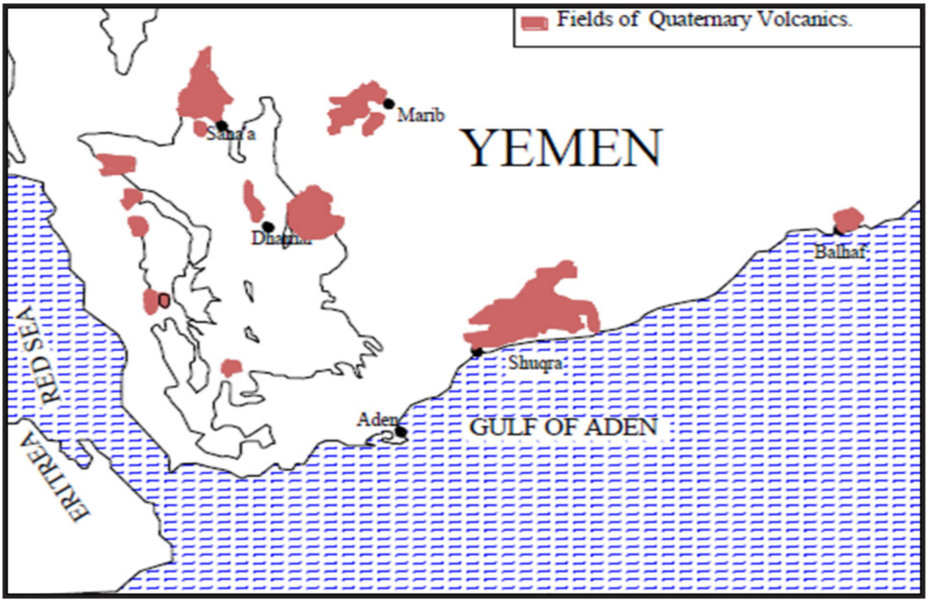

Figure 1: Main locations of Quaternary Granular Volcanic Ash in Yemen [2]

These GVA materials are associated with volcanic activity and characteristic in its natural state by light weight, rough surface, high porosity, low density, non-plastic particles, has very slight or no fine material with poorly gradations and other undesirable properties [4-7]. Due to the weak properties of this soil, it cannot be used as a foundation either for structures or pavement applications. It is popular solution, when founded such material, to replace it by good soil and carrying the removed GVA soil to landfill locations. Such solution is costly and the quantity of transported GVA soil increases with time which required new sites. Due to the huge amount of transported material, the problem in some city areas is becoming an environmental problem. It is clear that improving the properties of such soil for engineering purposes or discovery possible for uses it in building industry is essential. The available studying indicated practicability to producing lightweight concrete, lightweight masonry by using volcanic aggregate in concrete mixtures [8, 9].

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The other possible method to solving this problem is improving the physical properties of this soil and using it for engineering applications, cement-stabilized soil is utilized in a variety of geotechnical applications [10-12]. In this way, use stabilizer agent such as cement as the admixtures to improve the engineering properties of Granular volcanic ash material for the construction of pavement layers [13-19]. However, it is necessary to ensure this mixture has sufficient strength and durability to exposure the different environmental conditions. Many researchers used ultrasonic wave velocity (non-destructive method) to evaluate some of engineering properties of stabilized mixtures [20-22].

According to the Portland Cement Association (PCA) [23] and the American Concrete Institute (ACI) [24], the mixture procedures stipulate that cement can be added as a percentage of the weight of dry soil, with concentrations ranging from 2% to 11%. In addition, they recommend that a minimum strength be achieved after seven to 28 days of curing. However, there are relatively few studies available on the durability test, ultrasonic pulse velocity (UPV) test on cement-stabilized GVA, and strength for long time curing.

In this research the GVA materials will be mixes fine soil to improve the GVA gradation with different amount (0%, 10%, 20%, and 30 % by dry weight of GVA material) and stabilize using cement content (0, 2, 5 and 8 % by dry weight of GVA material), and curing for 7 and 28 days. These GVA-cement-fine soil mixture are evaluated the performance of the mixture to use in sub base coarse in pavement road in Yemen. The Performance criteria in this study involved compaction characteristics, strength characteristics, durability (wetting and drying) performance, and ultrasonic pulse velocity (UPV) performance.

2. Experimental Program

2.1. Material Used

2.1.1. Granular Volcanic ash (GVA) Materials

The GVA materials for this study came from Mthbah area located to the North West the city of Sana'a, the capital of Yemen; it is present in loose, uncemented layers at depths of between half a meter and several meters. The grain size distributions of the GVA materials are shown in Figure 2. The engineering characteristics of the GVA materials are summarized in Table 1; also, the chemical composition of the GVA materials is displayed in Table

2. Based on the Unified Soil Classification System, these GVA materials are categorized as Gravel with poorly graded (GP).

2.1.2. Fine soil

Fine soil was obtained from Shamlan region in the Sana'a city center is utilized. Figure 2 displays the fine soil's grain size distribution. Also, Table 1 summarizes the engineering characteristics of the fine soils; this fine soil is categorized by the Unified Soil Classification System (USCS) as clay low plasticity (CL).

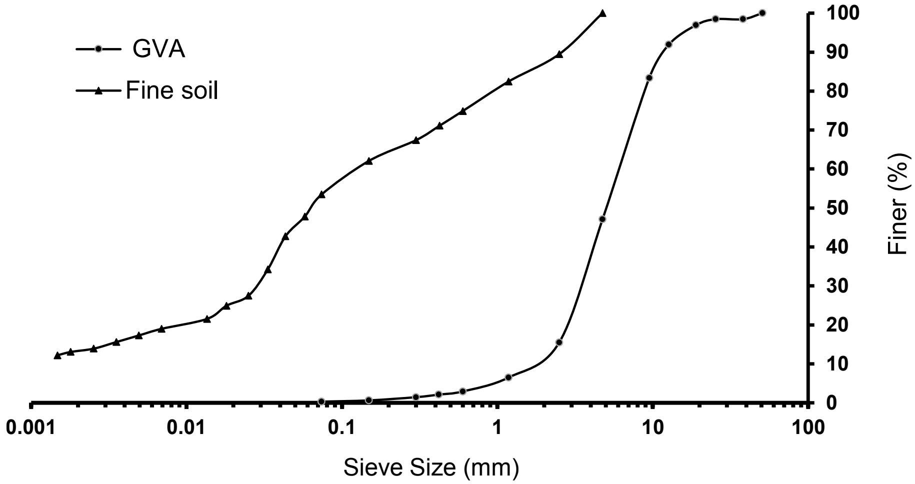

Figure 2: Grain size distribution curve of GVA and Fine soil

Table 1: Physical characteristics of GVA and Fine soil

Property	Value		Test Standard [25]
	GVA	Fine soil	
Apparent Specific Gravity, Gs	2.11	2.72	ASTM D 854 & ASTM C128
Water Absorption %	18.23	-	
Los Angeles abrasion %	55.9	-	ASTM C131
Liquid Limit, LL	Non-plastic	31.5	ASTM D 4318
Plasticity Index, P I	Non-plastic	5.3	

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Table 1: Continued

Property	Value		Test Standard [25]
	GVA	Fine soil	
Gravel (80 - 4.75 mm), %	52.93	0	ASTM D 421 & ASTM D 422
Sand (4.75 - 0.075 mm), %	46.77	46.52	
Silt & Clay, %	0.30	53.48	
Uniformity coefficient (Cu)	3	-	
Coefficient of curvature (Cc)	1.2	-	
Unified Classification System	(GP)	CL	ASTM D2487
AASHTO Classification System	A-1-a (0)	A-2-4	ASTM D3282
Fineness modulus	5.47	-	ASTM C125

2.1.3. Cement

Ordinary Portland cement (OPC) that is produced locally, which is a product of Amran cement factory was obtained and used as the cementing agent according to ASTM C150 [25] in the study. The cement grains have a specific gravity of 3.15, and Table 2 displays the cement's chemical composition.

2.1.4. Water

The tests use tap water, which may be distilled if necessary to comply with testing protocols in some cases.

2.2. GVA-Cement-Fine Soil Mixtures

The GVA was mixed with fine soil content at 0%, 10%, 20%, and 30% by dry weight of GVA. Next, the cement content was added to the dry GVA-fine soil mixture at 2%, 5%, and 8% by dry weight of GVA and mixed thoroughly to create a uniform color. Finally, the mixture was perfectly mixed and moistened with a chosen amount of water. The preparation time for the GVA-cement-fine soil mixture and compact was always less than the initial setting time, which is 45 minutes for Portland cement.

2.2.1. Compaction Characteristics of GVA-Cement-Fine Soil Mixtures

According to American Standard ASTM D 1557 [25], a series of modified Proctor compaction tests were conducted to determine the correlation between water content and dry unit weight (compaction curve) for GVA-cement-fine soil mixtures.

2.2.2. Sample preparation of GVA-Cement-Fine Soil Mixtures

Figure 3 illustrates cylindrical samples for the UCS, ITS, durability, and UPV tests were prepared by adding the specified cement content (2, 5, and 8% by dry weight of GVA), and fine soil content (0, 10, 20, and 30 % by dry weight of GVA) to dried GVA materials.

Figure 3: GVA-cement-fine soil samples for UCS, ITS, durability, and UPV tests

For each specimen, the dry mass of the GVA-cement-fine soil mixture was divided by the specimen's total volume to determine the target dry unit weight. Following the weighing of the GVA, fine, cement, and water, the dry GVA, cement, and fine soil were combined and mixed until the mixture took on a uniform color. Following the addition of optimum water content to the dry GVA-cement-fine soil mixture was blended until a homogenous paste was produced. The specimen was statically compacted in three layers (sing spacers as shown in Figure 5(b)) inside a lubricated cylindrical mold having a height of 140 mm and a diameter of 70 mm (h/d = 2.0) to the maximum dry density of the GVA-cement-fine soil mixture based on the modified Proctor compaction test. To bond with the next layer, the top of each layer was lightly scarified. After the molding process, the specimen was immediately extracted from the mold and its weight, diameter, and height were measured with accuracies of around 0.01 g and 0.1 mm, respectively. The samples were then placed inside plastic bags to prevent significant variations in moisture content. They were cured in a humid room at 23° ± 2°C for 7 and 28 days, with a relative humidity above 95%.

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3. Tests

3.1. UCS test

According to ASTM D1633 [25], an unconfined compressive strength test is conducted. The loading frame gets evaluated first in the process, also determines the units of the deformation dial gauge and the calibration constant for the proving ring. The specimens will be sheared at a rate of 1.25 mm per minute. Make sure the sample is a perfect right cylinder by measuring its initial height and diameter with calibrators. Consequently, in order to ascertain the average height and diameter, several measurements at different points along the sample will be necessary. Determine the total (wet) unit weight by weighing the soil sample, placing it into the loading frame, seats the proving ring, zeroing the dials, and recording the load applied at the specified vertical deformation values.

3.2. ITS Test

The Indirect Tensile Strength (ITS) test is carried out in compliance with Brazilian Standard Association NBR7222 [26], After that, the load was applied continuously at a rate of 1.25 mm per minute, and the strain was monitored during the test using a dial gauge, when the specimens failed, a vertical crack was found along their diameter. The tensile strength is calculated using the following equation:

$$\text{Indirect Tensile Strength} = 2P/\ (\pi\ d\ L)\ (\text{MPa})$$

Where d is the specimen diameter (in mm), L is the thickness of the sample (in mm), and P is the maximum load that applies (in N).

3.3. Durability (Wetting and Drying) Test

Prior to wet-dry cycles testing, each specimen was prepared and then placed in a room with a humidity level above 95% for seven and twenty-eight days. After the samples' 7 and 28-day curing times are up, they are removed from the curing room and put through the wetting-drying test. The samples were allowed to dry for 24 hours at room temperature and then submerged in water for an additional 24 hours as shown in Figure 4 illustrates. This process represents a 48-hour one cycle of drying and wetting. After the twelve wetting-drying cycles were completed, the samples were weighed, and each tested sample's moisture content was determined in order to calculate the weight loss of GVA-cement-fine soil samples using the following equation.

$$\text{weight loss } = \frac{(\text{ initial weight of a dry sample } - \text{weight of the dried sample after cycles of durability})}{\text{initial weight of a dry sample}} \text{ x } 100 \text{ (\%)}$$

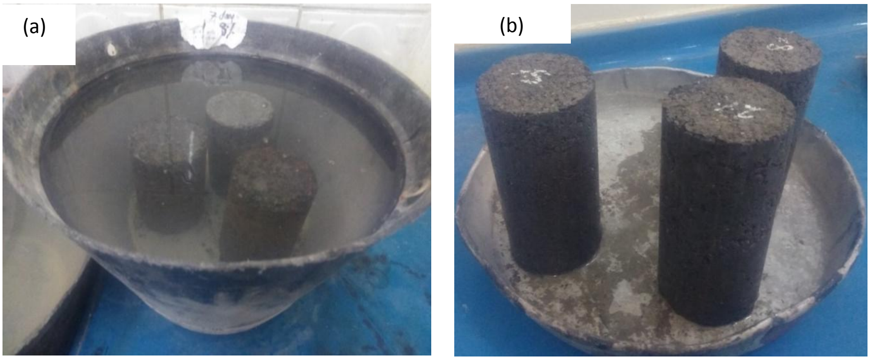

Figure 4: (a) Wetting and (b) Drying of GVA-cement-fine soil specimen

3.4. Ultrasonic Pulse Velocity (UPV) Test

After the 7 and 28-day curing period was up, the GVA-cement-fine soil specimen's dimensions were measured accurately, and the UPV was determined by contacting the transducers (with 50 mm diameter and 55 kHz frequency as seen in Figure 5(a)) at the ends of the samples with a water-based jelly for good coupling to ensure complete contact between the sample and transducers as indicated in Figure 5 (b). The equation was used to determine the UPV:

$$\text{Ultrasonic Pulse Velocity (UPV)} = L/(t) \quad ((m)/sec)$$

Where L is the specimen length (centimeters) and t is the transmission time (microseconds), as displayed on the PUNDIT-Plus digital screen.

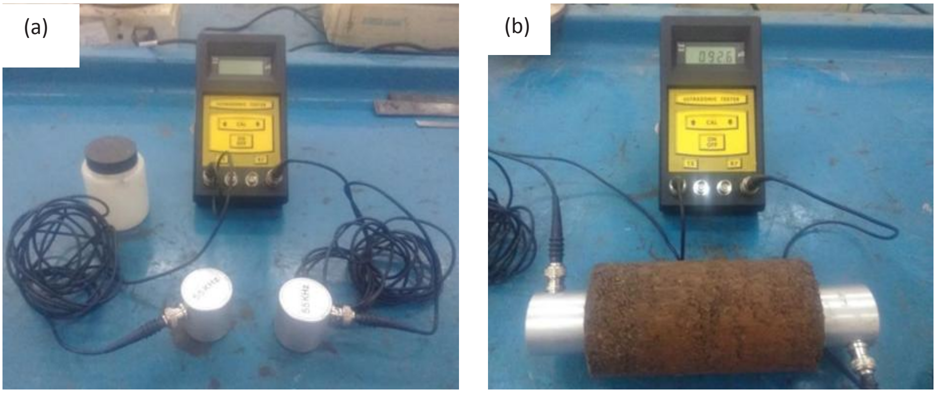

Figure 5: Ultrasonic Pulse Velocity device: (a) Test equipment, and (b) UPV measurement

4. Results and Discussion

4.1. Compaction Performance

4.1.1. Effect of the Compaction Energy Used on the Gradation of GVA Materials

Figure 6 shows the grain size distribution curve (GSDC) of GVA materials before and after using the modified Proctor compaction procedures to produce the samples. The figures reveal that GSDC has undergone major changes in the gradation and finesse modulus of coarse GVA materials, and a similar result was found by [27]. The finesse modulus (according to ASTM C125 [25]) before and after compaction was 5.47 and 4.22 respectively. For coarse GVA materials, the corresponding reduction in finesse modulus was −23%. The reduction in finesse modulus after compaction is related to the accumulation of fine aggregate resulting from the breakdown of the coarse aggregate in GVA materials, causing a reduction in cumulative percentage retained in sieves. Finally, the gradation of GVA materials was poorly graded gravel before compaction. However, gravel became poorly and well graded sand after compaction. This change in gradation is attributed to the abrasion of GVA materials under the effect of compaction energy.

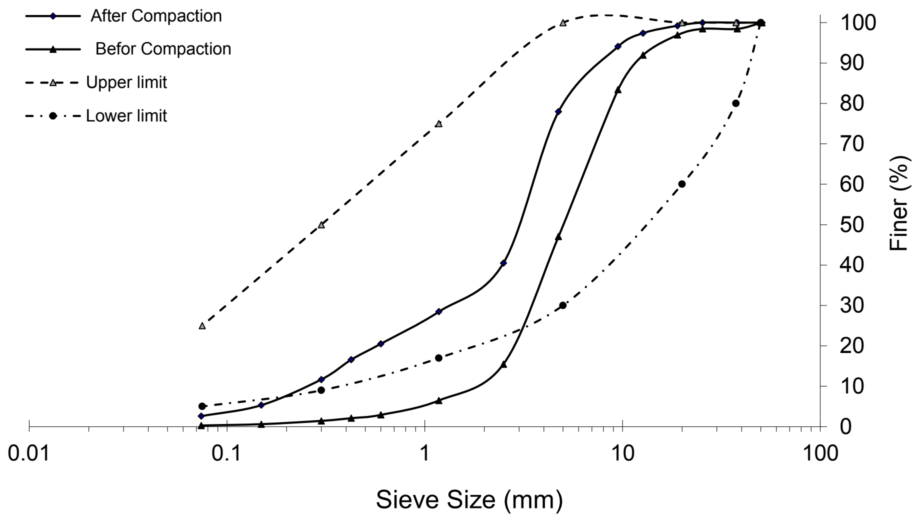

Figure 6: Grain size distribution curve of black GVA before, and after of compaction

4.1.2. Effect of Fine Soil in the Gradation of the GVA Mixture before and after Compaction

The density and strength of the pavement structure are influenced by the improved GVA gradation produced by blending with the fine soil and the mixture's particle size blend. The material used shall have grading within the limits for grading the sub base material in accordance with the construction specification [28], with the nominal maximum size of the GVA after compaction being 9.5 mm as shown in Table 2.

Table 2: The sub base materials' range of sieve grading [28]

Sieve Size (mm)		**37.5**	**20**	**5**	**1.18**	**0.3**	**0.075**
Passing %	Upper limit	100	100	100	75	50	25
	lower limit	80	60	30	17	9	5

Figure 7 through Figure 9 show the effect of adding fine soil on the grain size distribution curves of GVA before and after compaction. The grain size distribution curves in Figure 8 shows that the GVA has a deficit in fine particles. It is therefore not in accordance with the specification. The gradation is improved by blending a trial proportion of fine soil, and the ideal proportioning is discovered to fulfill the specification requirement. From a gradation point of view, 20% and 30% of the fine soil trails have good

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proportioning. Figure 7 through Figure 9 summarize the above point.

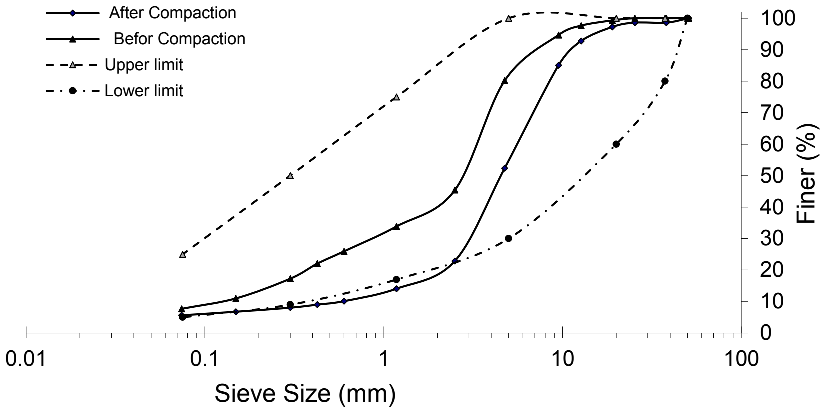

Figure 7: Gradation of GVA with 10% fine soil before and after compaction

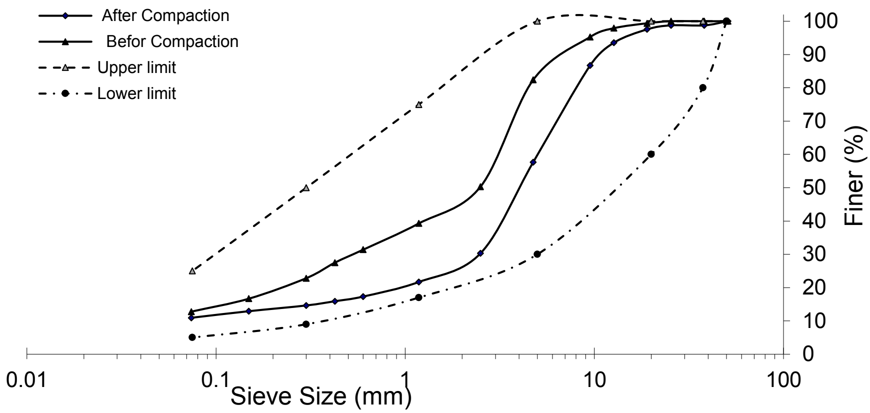

Figure 8: Gradation of GVA with 20% fine soil before and after compaction

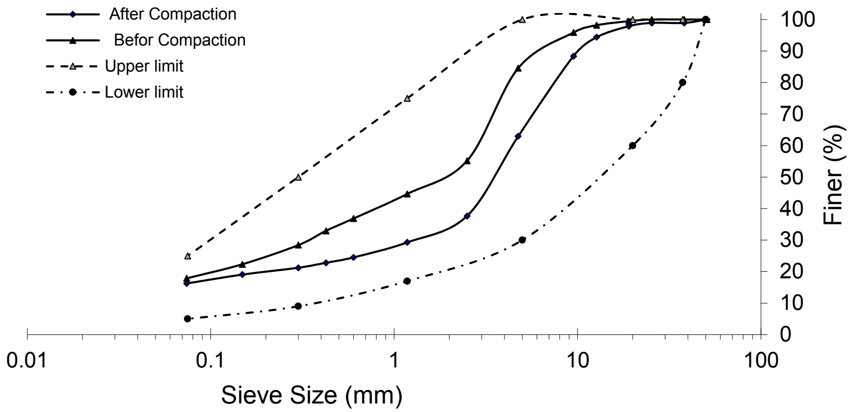

Figure 9: Gradation of GVA with 30% fine soil before and after compaction

It is apparent in Figure 6 through Figure 9 how the modified compaction method caused more crushing for the GVA. The results of the laboratory test illustrate that, in spite of an improvement in gradation due to the weak GVA, break down under compaction still requires additional fine grained to meet specifications. The ideal amount of fine soils is needed for construction in order to guarantee that the final granular surface is stable enough to support paving equipment without disturbing the surface. Additionally, some fines are needed in order for the granular material to bind and the particles to interlock when the sub base is compacted. If not, when loaded, they would shear.

4.1.3. Effect of Cement Content, and Fine Soil Content on GVA Material Compaction Curve Characteristics

The relationship between the dry densities and moisture contents for GVA mixed with 0, 10, 20, and 30% of fine soil separately, and stabilized by 0, 2, 5, and 8% cement content, is depicted in Figure 10 through Figure 13. In general, it is apparent that the increase in dry density with moisture content at the dry side of the optimum moisture content, as well as the decrease in the curve at the wet side of the optimum moisture content, are nearly similar for all GVA-cement-fine soil mixture at different cement content, and different fine content. This remains equally for all mixtures of various fine soil contents separately. This indicated that as the cement content rises, the mixture's densities become less sensitive to the addition of water. This may have been explained by cement, which is a fine soil, filling the spaces between the GVA particles. Cement has a specific gravity of 3.15, while fine soil has a specific

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gravity of 2.72, which is greater than that of GVA materials, which has a specific gravity of 2.11. Increasing the fills causes the dry density of the GVA-cement-fine soil mixture to rise. However, as the fine content (cement and fine soil) increases, the mixture becomes more susceptible to water, increasing optimum molding content. Similar relationships were found by Subhi [18].

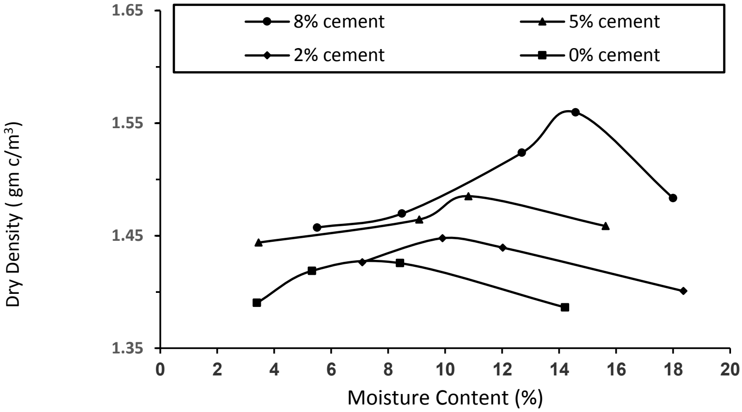

Figure 10: Compaction curves of GVA with 0% fine soil stabilized by different cement content

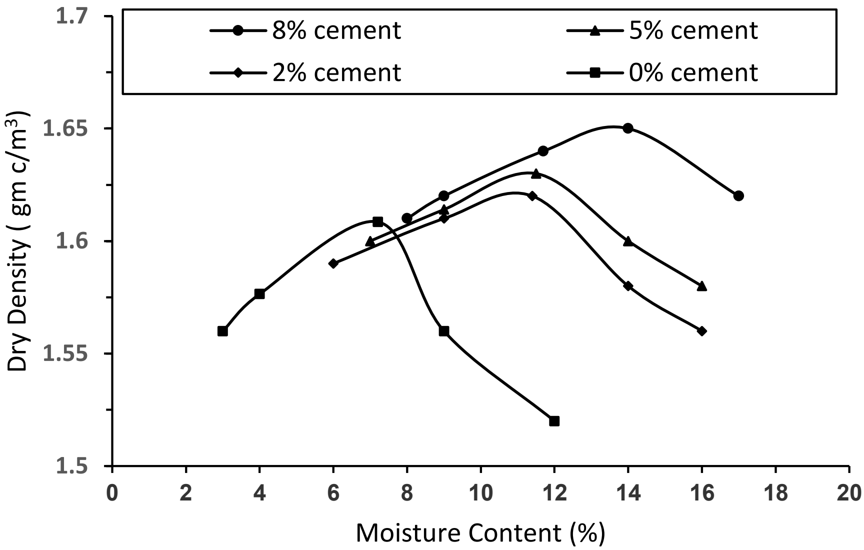

Figure 11: Compaction curves of GVA with 10% fine soil stabilized by different cement content

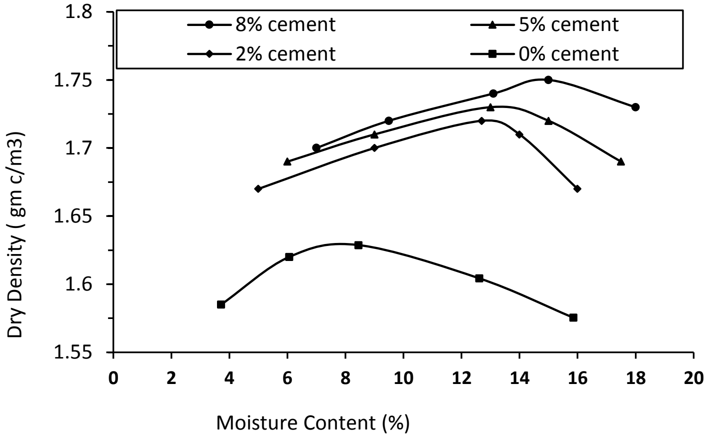

Figure 12: Compaction curves of GVA with 20% fine soil stabilized by different cement content

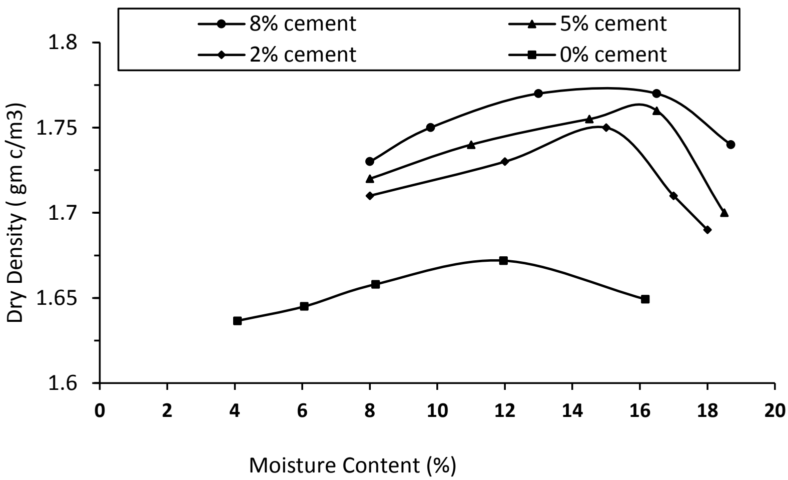

Figure 13: Compaction curves of GVA with 30% fine soil stabilized by different cement content

The effect of fine soil and cement content on the maximum dry density of GVA mixed with 0%, 10%, 20%, and 30% fine soil and those stabilized with 2%, 5%, and 8% of cement shown in Figure 14 and Figure 15. Figure 14 displays that the maximum dry density increases by high rate with increase the fine content up to 20% after that for example at 30 % fine soil the rate of density increase become lowered. When percentages of fine soil are added, the maximum dry density increases at a nearly constant rate. This could be explained by the 20% fine soil that fills the spaces between the GVA particles;

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any additional fine soil causes the GVA to float in the fine soil and reduces grain-to-grain friction. For the mixtures stabilized with different proportions of cement, these behaviors are comparable. Subhi displayed comparable actions [18].

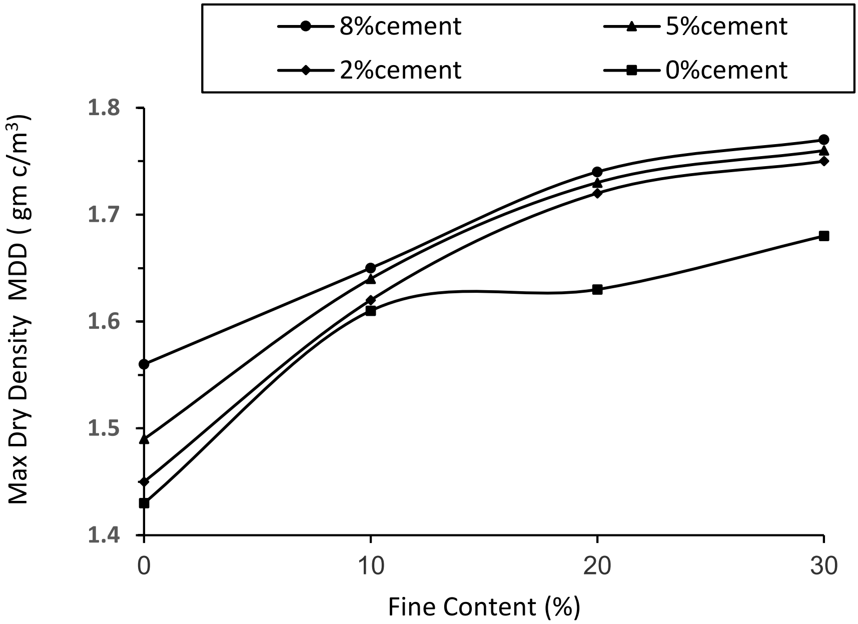

Figure 14: Effect of fine clay content on MDD of GVA-cement-fine soil mixture

However, the MDD for GVA-fine soil mixture is increase with increase of cement content up to 5% cement content, after that for example at 8% cement the MDD is almost constant. Furthermore, from Figure 15 the increase of cement content causes increase in the MDD of the mixture at different fine content, this increase in MDD up to 20% fine is almost not that effect.

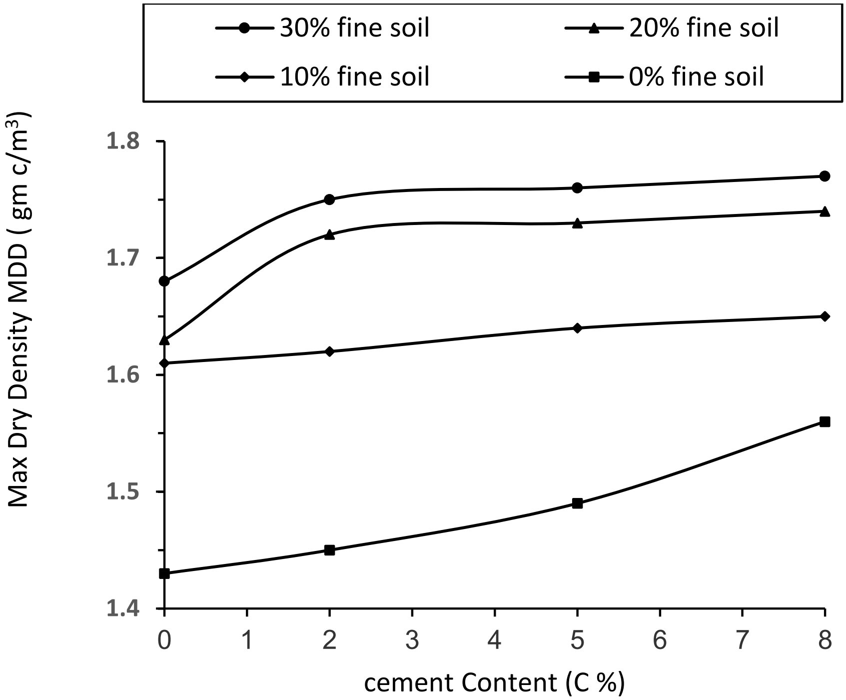

Figure 15: Effect of cement content on MDD of GVA-cement-fine soil mixture

4.2. Strength Performance

4.2.1. Effect of Fine Soil Content, Cement Content, and Curing Time on UCS of GVA-Cement-Fine Soil Mixture

The relationships between the UCS and cement content for GVA mixed with 0%, 10%, 20%, and 30% of fine soil after curing times of 7 and 28 days are shown in Figure 16 and Figure 17, respectively. The UCS of the GVA-cement-fine soil mixture increases as the cement content, fine soil content, and curing time increase, as indicated by the figures below. This phenomenon is explained by the increase in fine content (fine soil and cement content), which permits the cement's hydration products to fill the matrixes pores and strengthens the structure's rigidity by forming multiple hard bonds between the GVA particles. Furthermore, an increase in UCS at the same cement amount was caused by a long curing period. This phenomenon is expected to be attributed to hardened GVA-cement-fine soil structures and pore reduction due to the long curing process, leading to an increase in strength as mention before.

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Finally, the UCS cement content relationship as shown in figures are approximately linear and exponential at 0% fine soil after curing times of 7 and 28 days, respectively. These relationships are change to become logarithm curve with increase of fine content in the GVA-cement-fine soil mixture. As a consequence of the results shown in Figure 16, and Figure 17 GVA with 20% fine soil and 5% cement content fulfilled the criteria for utilizing cement-stabilized GVA for the construction of sub base coarse for medium traffic loads or base coarse for low-traffic roads. On the other hand, GVA with 20% fine soil and 8% cement content fulfilled the criteria for utilizing cement-stabilized GVA for the construction of base coarse for medium-traffic roads according to Australian road design guidelines [29].

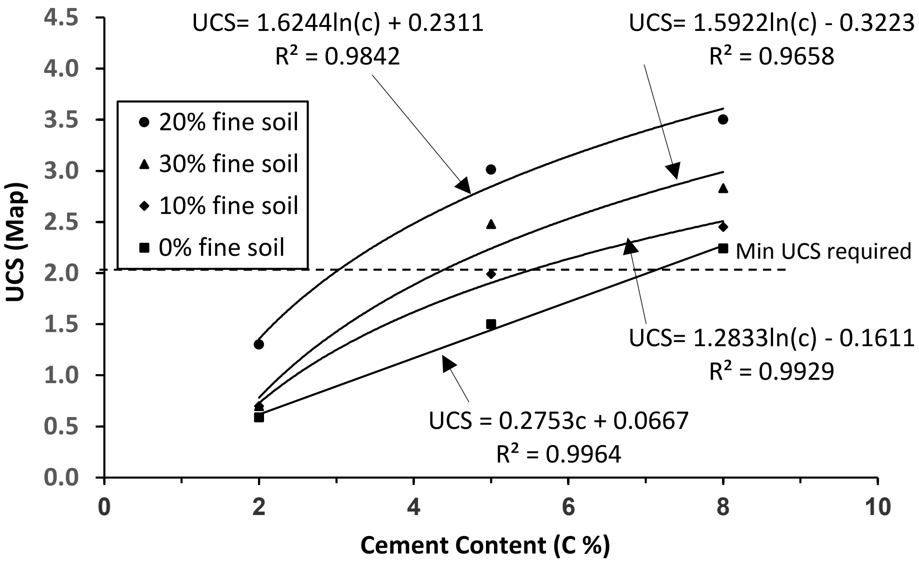

Figure 16: UCS of GVA after 7 days curing at different cement and fine contents

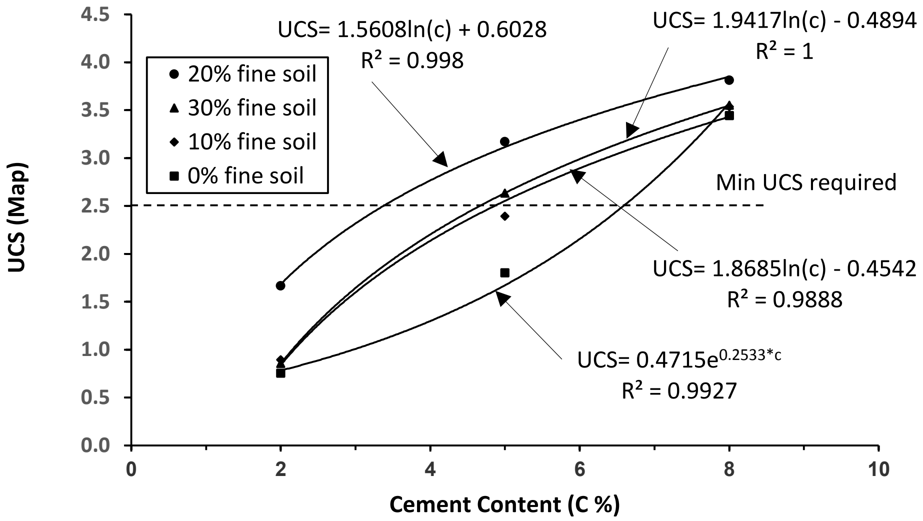

Figure 17: UCS of GVA after 28 days curing at different cement and fine contents

The primary goal of adding the fine soil into the GVA mixture was to improve the GVA gradation and increase coherence as mention before. The influence of fine soil in the UCS of the GVA-cement-fine soil mixture is depicted in Figure 18 after seven and twenty-eight days of curing. According to the evidence, UCS increases more quickly with increasing fine soil content up to a certain threshold (20%), after which it begins to decline. The same behavior was observed for mixtures stabilized with varying percentages of cement at varying curing times (7 and 28 days). The optimum value for fine content is found to be 20% for all mixtures, despite each exhibiting a different maximum UCS. Filling the spaces between GVA particles and increasing density to the optimal level of fine soil causes an increase in UCS, which is then decreased by reducing the friction between the GVA grains because a large amount of fines has no grain-to-grain contact and the GVA grained float in the fine soil.

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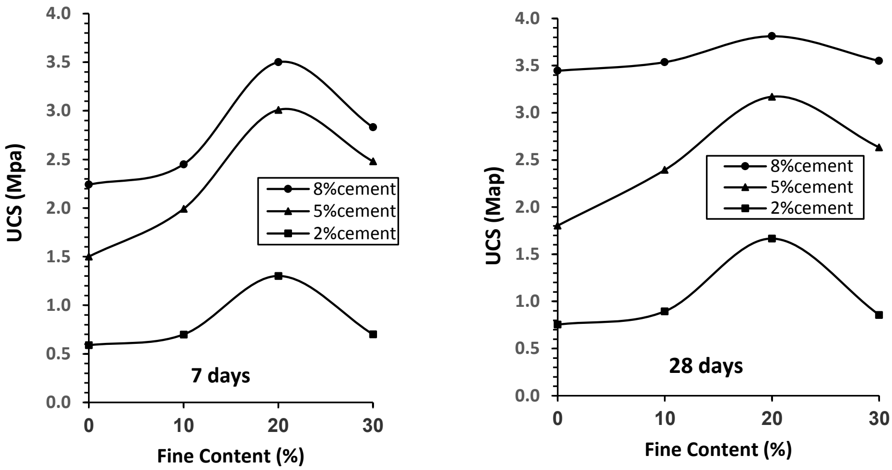

Figure 18: Effect of fine soil content on UCS of GVA-cement-fine soil mixture after curing times of 7 and 28 days

4.2.2. Effect of Cement Content, Fine Soil Content, and Curing Time on ITS of GVA-Cement-Fine Soil Mixture

The relationships between the ITS and cement content for GVA-cement mixed with 0%, 10%, 20%, and 30% of fine soil after curing times of 7 and 28 days are shown in Figure 19 and Figure 20, respectively. As shown in the figures, the ITS of GVA-cement-fine soil mixture increase with increase cement content, fine soil, and curing time. The ITS cement content relationship as shown in figures are approximately linear at 0 % of fine soil after curing times of 7 and 28 days. This relationship is change to become logarithm curve with increase of fine content in the GVA-cement mixture. This change contributed to the variation in the density, and water content of the mixture. Therefore, GVA mixed by 10% fine soil and treated by cement at a 5% amount satisfy the standards for using GVA in low-traffic pavement construction according to the South African Pavement Engineering Manual (SAPEM) standards for infrastructure agencies [30].

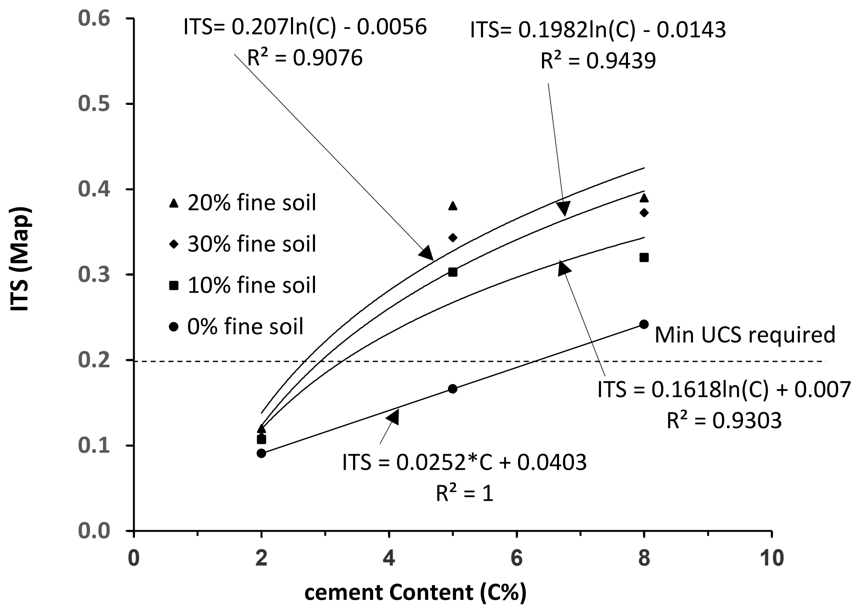

Figure 19: ITS of GVA after 7 days curing at different cement and fine contents

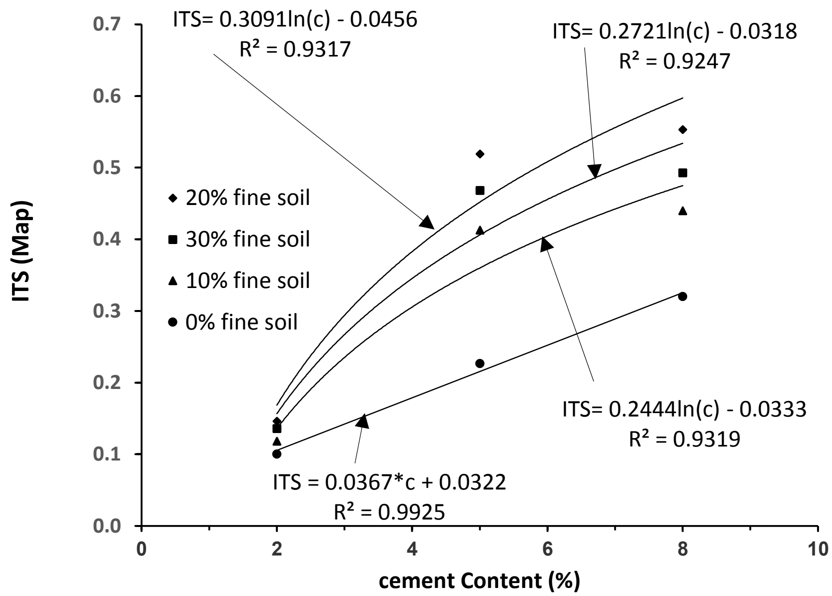

Figure 20: ITS of GVA after 28 days curing at different cement and fine contents

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As mention before the purposes of addition the fine soil to GVA was to improve the grain size distribution curve of GVA. Figure 21 shows the effect of increase of fine soil content on the indirect tensile strength of the GVA-cement-fine soil samples at different cement content and different curing time. As shown the ITS values of GVA-cement-fine soil mixtures increased with increasing the fine soil content until 20%. Above 20% fine content (for example 30%), the ITS-value decreased this behavior is clear at cement content (5% and 8%). Similar behavior obtained for the mixture at different curing times (7 and 28 days). Similar results were obtained when the unconfined compressive strength was measured. The ideal level of fine content is found to be 20% for all mixtures, despite each having a different maximum ITS. Filling in the spaces between GVA particles and raising density to the optimal level of fine soil may increase ITS with fine soil because this increases the inter particle friction. Subsequently, any increase in fine soil causes the GVA particles to become submerged in the fine soil, which reduces inter particle friction and results in drops in ITS.

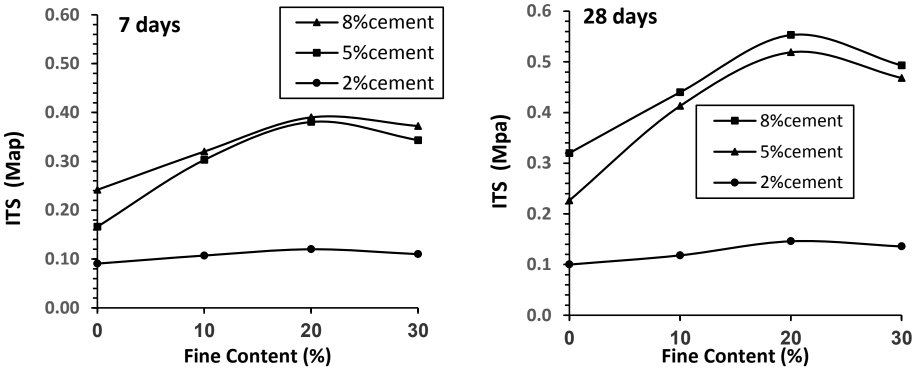

Figure 21: Effect of fine soil content on ITS of GVA-cement-fine soil mixture after curing times of 7 and 28 days

4.3. Durability Performance of GVA-Cement-Fine Soil Mixture

4.3.1. Effect of the Wetting-Drying Cycles on Loss of Weight of GVA-Cement-Fine Soil Mixture

Figure 22 depicts the effect of cement content, fine content, and curing time on the weight loss of GVA-cement-fine soil mixtures. The figure shows that as fine content, cement content, and cure time increase, weight loss decreases. This decrease in weight loss with increasing fine soil, cement content, and curing time is attributed to the strengthening of bonds between the GVA grains, as well as the voids between grains is decreased due to the increase in fine content, which made good gradation in the mixture. ASTM D559 indicates that the weight loss of soil-cement mixtures after 12 wetting-drying cycles should not exceed 14% [31]. Therefore, the GVA fulfill the weight loss criteria at 2% cement without or with fine soil.

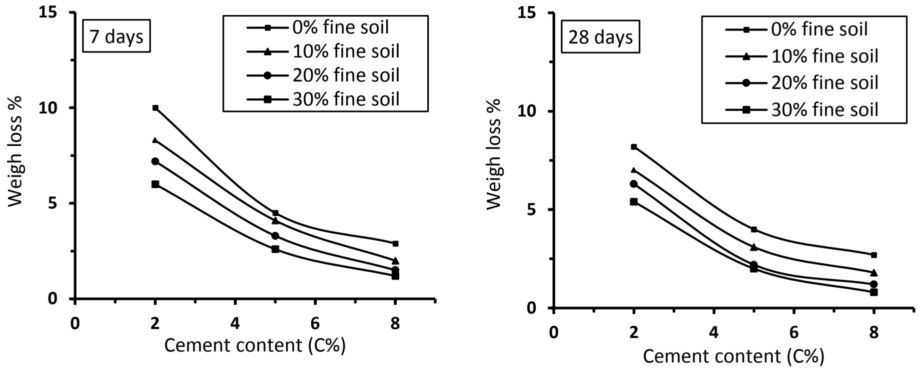

Figure 22: Variation of weight loss with cement content GVA-cement-fine soil mixture after 7- and 28-days curing

4.4. Ultrasonic Pulse Velocity (UPV) Performance of GVA-Cement-Fine Soil Mixture

4.4.1. Effect of the Cement Content, Fine Content, and Curing Time on UPV

Figure 23 show the effect of cement content, fine soil content and curing time on the UPV of the GVA mixed by different fine content and stabilized by different cement content then curing for 7, and 28 days. Typically, the UPV increases as cement content, fine content and curing time increase; these factors indicate an increase in strength and stiffness. The increase UPV with increase fine content might be attributed to the spaces between grains reduces with increase of fine causes increase in the density and reduce on the porosity of the mixture.

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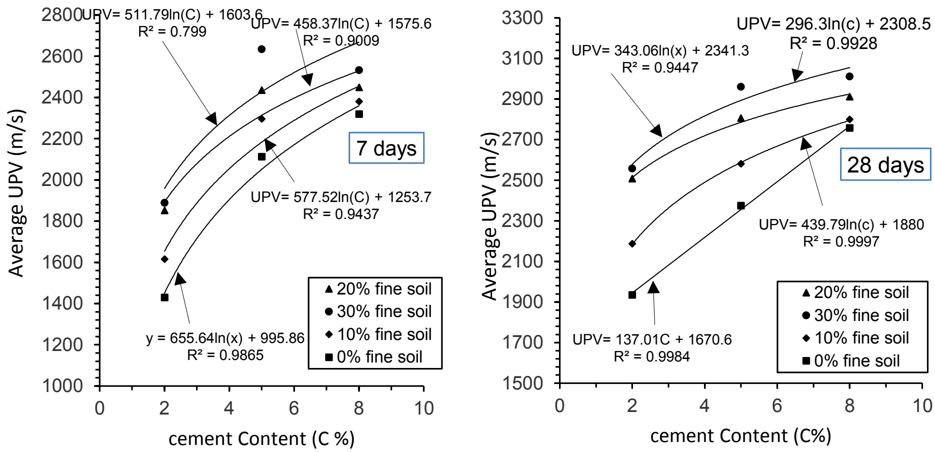

Figure 23: UPV of GVA after 7- and 28-days curing at different cement and fine contents

4.4.2. Correlation of UPV with UCS and ITS of GVA-Cement-Fine Soil Mixture

Figure 24 illustrates the correlation between UCS and UPV, with a power correlation coefficient of determination (R2) of 0.90. Additionally, Figure 25 displays the correlation between ITS and UPV, which is represented by power regression with R2=0.88, indicating a very strong correlation between ITS and UPV of cement stabilized GVA material. Furthermore, as seen in the Figure 24, and Figure 25, an increase in UCS and ITS of the GVA-cement-fine soil samples results in an increase in sounding velocity time is attributed to the strengthening of bonds between the GVA grains. With the nondestructive method using UPV, these correlations can be used to estimate the values of the unconfined compression strength, and indirect tensile strength of the GVA-cement-fine soil mixture.

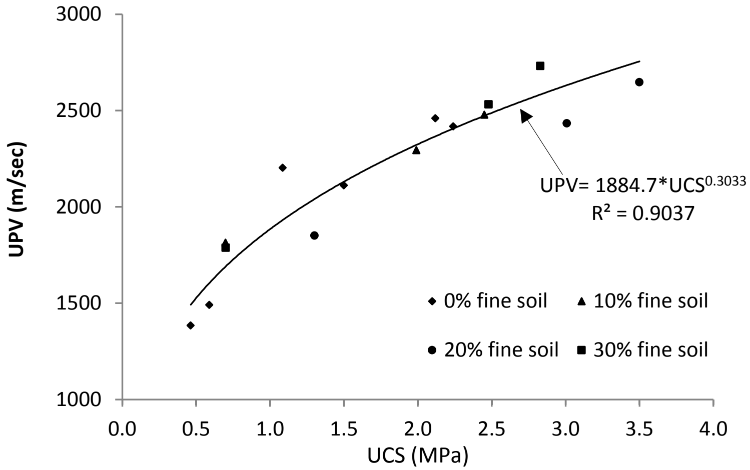

Figure 24: Relationship of UPV with UCS for GVA-cement-fine soil mixture

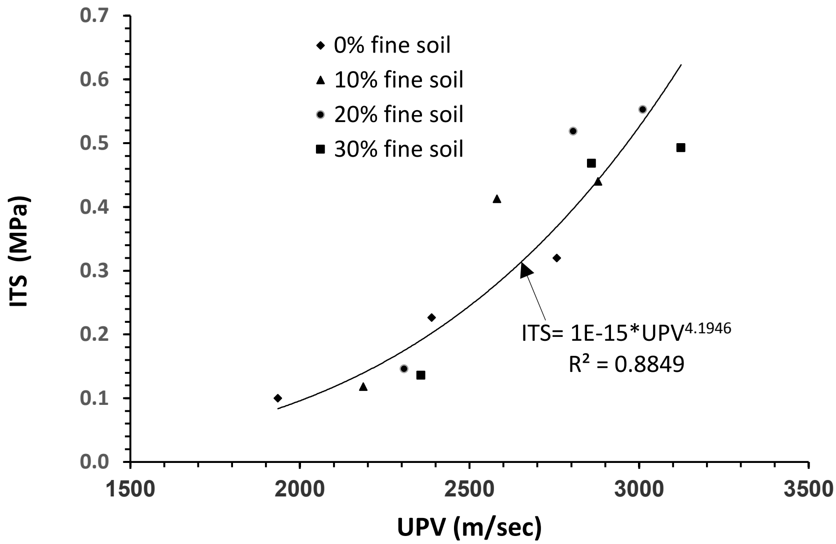

Figure 25: Relationship of ITS with UPV of GVA-cement-fine soil samples

5.Conclusions

Considering the test results, the following conclusions can be drawn:

- The reduction in finesse modulus due to the compaction energy in coarse GVA materials was 23%.

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- Mixing GVA with fine soil enhances gradation, and the best proportioning is discovered to meet sub base specifications at 20% and 30% fine soil content.

- The maximum dry density of the GVA-cement-fine soil mixture increases with the increase of fine content.

- Up to a certain percentage (20%), an increase in fine soil content results in an accelerated rise in both UCS and ITS. After that, UCS and ITS begin to decline.

- The UCS, and IT'S with cement content relationship are become logarithm curve with increase of fine content in the GVA-cement-fine soil mixture.

- Cement-stabilized GVA met the requirements for sub-base coarse for medium-traffic roads when it contained 20% fine soil and 5% cement.

- The weight loss decreases with increasing cement and fine content levels as well as with longer curing times and the GVA fulfil the weight loss criteria at 2% cement without or with fine soil.

- An increase in fine content and cement content causes increases in the ultrasonic velocity.

- A good correlation between the UPV and the strength of the GVA-cement-fine soil mixture in both terms UCS, and ITS.

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