Effect of Replacing Conventional Base Materials with Granular Volcanic Ash on Engineering Properties

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https://doi.org/10.59222/ustjet.1.1.4

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Abstract:

Granular Volcanic Ash (GVA) is a material of volcanic activity; it has a rough surface, a low specific gravity, and a high porosity because of the structures of the minerals in it. The purpose of this study was to find a way to utilize this waste material, which is widely distributed across Yemen, by using GVA for the placement of conventional coarse aggregate (basalt aggregate) while constructing roads. In this study, Red and Black GVA materials were combined with conventional coarse aggregate for use in the construction of pavement. Base coarse materials were blended with GVA aggregate and examined for their engineering characteristics in an experimental study. Conventional coarse aggregate was partially replaced by five replacement levels from GVA, corresponding to 10%, 20%, 30%, 40%, and 50% of the dry aggregate`s total weight, were applied. As a control, a sample with no volcanic ash had been used. According to the results of experiment tests includes: density, California bearing ratio (CBR), abrasion percentage, and permeability test, it is possible to replace some of the basalt aggregates with GVA. Results showed that the engineering properties of base coarse materials specifications for CBR, and abrasion percentage were satisfied for volcanic ash percentages up to 20%.

Keywords: Granular Volcanic Ash, Sana`a, Yemen, basalt aggregate, density, CBR, abrasion, permeability.

https://doi.org/10.59222/ustjet.1.1.4

تأثير استبدال مواد طبقة الاساس التقليدية بالرماد البركاني الحبيبي على الخواص الهندسية

الملخص:

يعتبر الرماد البركاني الحبيبي من المواد الناتجة عن النشاط البركاني؛ يمتاز بسطح خشن، ووزن نوعي منخفض، ومسامية عالية ويرجع ذلك الى تركيب المعادن الموجودة فيها. الغرض من هذه الدراسة هو إيجاد طريقة للاستفادة من هذه المواد، والتي تنتشر على مساحة واسعة في الجمهورية اليمنية وتصنف كنفايات، وذلك عن طريق استخدامها كبديل عن الركام الخشن التقليدي (ركام البازلت) المستخدم في بناء طبقات الرصف المرن للطرق. في هذه الدراسة التجريبية تم دراسة الخصائص الهندسية لتربة الاساس الناتجة من استخدام نوعين من مواد الرماد البركاني الحبيبي تم الاشارة إليهم بالرماد البركاني الأحمر والأسود كبديل جزئي عن الركام الخشن التقليدي. حيث تم استبدال مواد الركام الخشن التقليدي جزئيًا بمواد الرماد البركاني الخشنة بنسبة 10 %، 20 %، 30 %، 40 %، و50 % من الوزن الإجمالي للركام الجاف. كما تم اعتبار عينة الركام التقليدي مع عدم وجود الرماد البركاني كمرجعية. ووفق لنتائج الاختبارات والتي شملت: الكثافة، ونسبة تحمل كاليفورنيا، ونسبة التآكل، واختبار النفاذية، فإنه من الممكن استبدال بعض ركام البازلت بالرماد البركاني الحبيبي. حيث أظهرت نتائج نسبة تحمل كاليفورنيا ونسبة التآكل أن الخواص الهندسية لخليط الركام التقليدي والرماد البركاني الحبيبي كانت محققة عند نسبة استبدال بالرماد البركاني تصل إلى 20 % كحد اقصى.

الكلمات المفتاحية: الرماد البركاني الحبيبي، صنعاء، اليمن، ركام البازلت، الكثافة، نسبة تحمل كاليفورنيا، التآكل، النفاذية.

https://doi.org/10.59222/ustjet.1.1.4

1. Introduction

Granular Volcanic Ash (GVA) materials are widely dispersed throughout Yemen. It covers an estimated area of more than 17,000 km2 of Yemen's total land area [1] as seen in Figure 1.

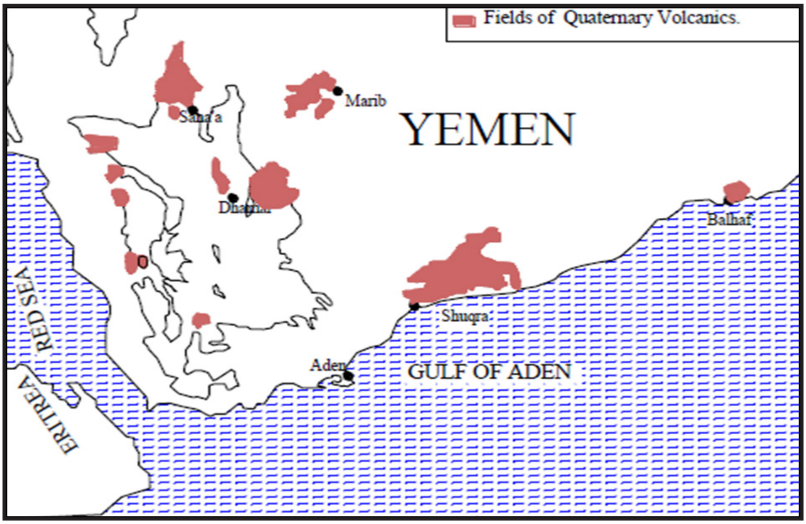

Figure 1: Main locations of Quaternary GVA in Yemen [1]

These materials, which have been related to historical volcanic activity, range in color from dark gray to black to red color [2, 3]. GVA materials are considered as natural aggregate, easy to excavate, light in weight, have a rough surface, have a low specific gravity, contains a non-plastic particles with poor gradations, and have a high void ratio, which makes them influential for abrasion of materials and water absorption [4, 5]. As a result of their strength and other engineering characteristics, these materials have been considered undesirable mainly because they do not meet the requirements for use as a foundation for buildings or pavement applications. Afterward, normally rejected in favor of expensive alternatives like crushed stone [6, 7]. However, because these options are frequently unavailable nearby, transporting huge numbers in vehicles causes extra costs and delays. Furthermore, because crushed stone is in such great demand, its scarcity, along with increasing fuel costs, has increased the cost of the construction of roads. Furthermore, the production of crushed stone requires drilling and crushing, both of which generate environmentally hazardous dust. Therefore, the cost of the road project might be decreased by properly using locally accessible GVA aggregate as the base coarse rather than crushed standard base course [8].

https://doi.org/10.59222/ustjet.1.1.4

According to [9], using Cinder-Aggregate in the sub-base layer as a 50% substitution for typical road aggregates results in an economical pavement construction with a savings of around 7800 $ per km length of road.

For the purpose of manufacturing (lightweight) concrete and lightweight masonry units, some research has been done to examine the effects of using volcanic aggregate [10, 11].

Furthermore, some researcher [1215-] carried out research to improve the engineering properties of volcanic ash by stabilizing it using a chemical binder like cement. Also, [16] investigated the use of volcanic ash as a partial substitute for conventional basalt aggregate in hot asphalt concrete mixtures at 0%, 10%, 20%, and 30% of the total weight of the dry aggregate.

The study covers testing and mixing base coarse materials with GVA to evaluate the changes in the characteristics of mixed materials. Most of the engineering characteristics of the base coarse materials when mixed with GVA will be evaluated in this study. Maximum dry density, optimum moisture content, California bearing ratio (CBR), abrasion, and permeability of mixed materials are some of the engineering characteristics that are desired.

2. Objective of the study

The objectives of this study are to:

- Use mechanical stabilization to partially replace crushed aggregate base course materials with Granular Volcanic Ash (GVA) for flexible pavements.
- Participate in manage the huge quantities of volcanic ash that are actually available but are considered as waste, by applying it to the construction of roads.

3. Research Methodology

3.1. Materials and methods

The research was applied on base coarse material that included a Basalt aggregate, Granular Volcanic Ash (GVA) in addition to the fine soil as filler with constant percent (10% of total weight of dry aggregate).

3.2. Material used

3.2.1. Aggregate and filler

Two types of aggregate were used in this study; basalt aggregate, which is the most available and frequently used type of aggregate in road construction by local agencies in Yemen region, and GVA aggregate. The basalt aggregate was partially replaced with the volcanic ash. Six volcanic ash percentages were investigated, 0%, 10%, 20%, 30%, 40% and 50% of total weight of dry aggregate, based on [9, 16].

3.2.1.1. Basalt aggregate

Basalt aggregates as shown in Figure 2 (c) was collected from Sana'a area and tested to determine its basic properties. The results are shown in Table 1.

3.2.1.2. Granular Volcanic Ash (GVA)

Two types of GVA materials were used in this study as present in Figure 2. Visually, these GVA types different in color, one type is red color (known as red GVA), and the other type is gray to black (known as black GVA).

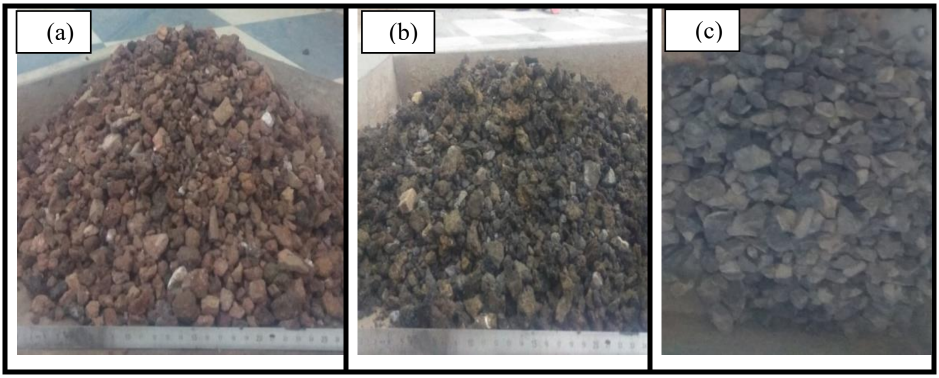

Figure 2: Aggregate of red GVA (a), black GVA (b), and basalt (c)

The GVA materials had been collected in the Mathbah area, located to the northwest of Yemen`s capital Sana`a. Tables 1&2 list the physical characteristics of two GVA materials. The Unified Soil Classification System and ASTM D 2487 [15] classify these GVA materials as poorly-graded Gravel (GP).

3.2.1.3. Fine soil

Fine soil from Shamlan in the Sana`a city center is utilized. Table 1 lists the characteristics of fine soil.

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Table 1: Physical characteristics of basalt, GVA aggregates and fine soil

Property	Value				Test Standard [15]
	Basalt Aggregate	Black GVA	Red GVA	Fine soil	
Apparent Specific Gravity, Gs	2.76	2.11	2.51	2.72	ASTM D 854 & ASTM C128
Water Absorption %	0.71	18.23	13.37	-	
Los Angeles abrasion %	24.5	55.9	48	-	ASTM C131
Liquid Limit, LL	Non-plastic	Non-plastic	Non-plastic	31.5	ASTM D 4318
Plasticity Index, P I	Non-plastic	Non-plastic	Non-plastic	5.3	
Gravel (80 - 4.75 mm), %	86.20	52.93	79.29	0	ASTM D 421 & ASTM D 422
Sand (4.75 - 0.075 mm), %	13.8	46.77	20.31	46.52	
Silt & Clay, %	0	0.30	0.4	53.48	
Uniformity coefficient (Cu)	-	3	1	-	
Coefficient of curvature (Cc)	-	1.2	2.3	-	
Unified Classification System	(GP)	(GP)	(GP)	CL	ASTM D2487
AASHTO Classification System	A-1-a (0)	A-1-a (0)	A-1-a (0)	A-2-4	ASTM D3282
Fineness modulus	-	5.47	5.26	-	ASTM C125

Table 2: Chemical composition of volcanic ash

Component	SiO2	Al2O3	Fe2O3	CaO
Percentage	68.53	14.32	9.45	5.89

Source: [13].

3.3. Aggregate combination

Basalt aggregate and GVA were combined to form the selected gradation used see Figure 3. In the study, only two sizes of volcanic ash particles were used. The first size was the one passing sieve No 34/ in (19 mm) and retained on sieve No. 12/ in (12.7 mm) and the second size was the one passing sieve No. 38/ in (9.5 mm) and retained on No 4 (4.75 mm). These two portions were found to form the bulk quantity of volcanic ash in its natural state and therefore the use of these portions is expected to be economically feasible.

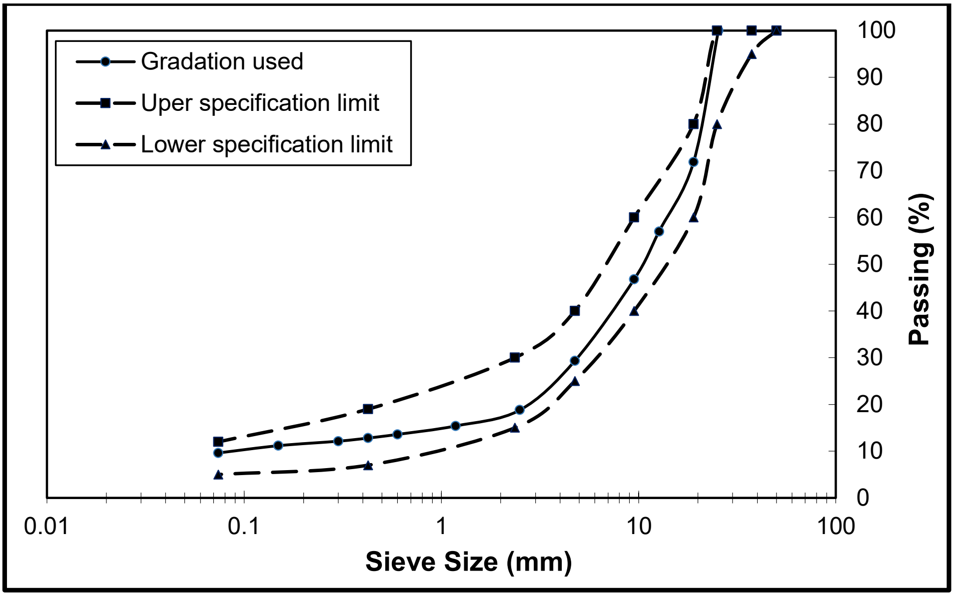

Figure 3: Gradation used

3.4. Design of mixtures

At ratios ranging from 0 to 50% of the total dry aggregate materials, samples of base materials were combined with GVA. The sample with 0% GVA was generated and evaluated as a control sample. Sieve analyses were performed in accordance to ASTM C136 [15].Maximum dry density tests were carried out in accordance with ASTM D698[15]. CBR was carried out in accordance with ASTM D4429 [15]. Los Angeles conducted tests for abrasion value in accordance with ASTM C131 [15], permeability in accordance with ASTM D2434 [15].

4.Results and discussion

4.1.Effect of volcanic ash content on the compaction characteristics of the mixes

Modified proctor compaction test was conducted to determine the compaction properties of base-GVA material mixes at 0, 10%, 20%, 30%, 40%, and 50% GVA from the total dry of the aggregate. Results are presented in Figures 4 & 5 and Table 3.

As expected, and due to lower specific gravity of GVA when compared to basalt aggregate, it has been found from the compaction test results that maximum dry density values decrease as the percentage of GVA materials

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increases, as shown in Figure 5. Further, this decrease depends on the type of GVA. The maximum dry density of base-Red GVA materials is higher than base-Black GVA at the same percent, especially for ratios greater than 10%, this being due to different specific gravities of GVA types. On the other hand, optimum moisture content (OMC) values nearly remain constant when GVA % increases as shown in Figure 4.

Table 3: Compaction characteristics of different mixes

S.NO	Percentage Replacement of GVA (%)		Maximum Dry density (g/cm3)		Optimum moisture content %	
	Basalt Aggregate %	GVA Aggregate %	Black GVA	Red GVA	Black GVA	Red GVA
Mix1	100	0	2.1	2.1	6.7	6.7
Mix2	90	10	2.04	2.04	7.1	7.2
Mix3	80	20	1.95	2.03	7.3	7.4
Mix4	70	30	1.89	1.93	7.4	7.6
Mix5	60	40	1.73	1.89	7	7.5
Mix6	50	50	1.66	1.82	6.9	7.4

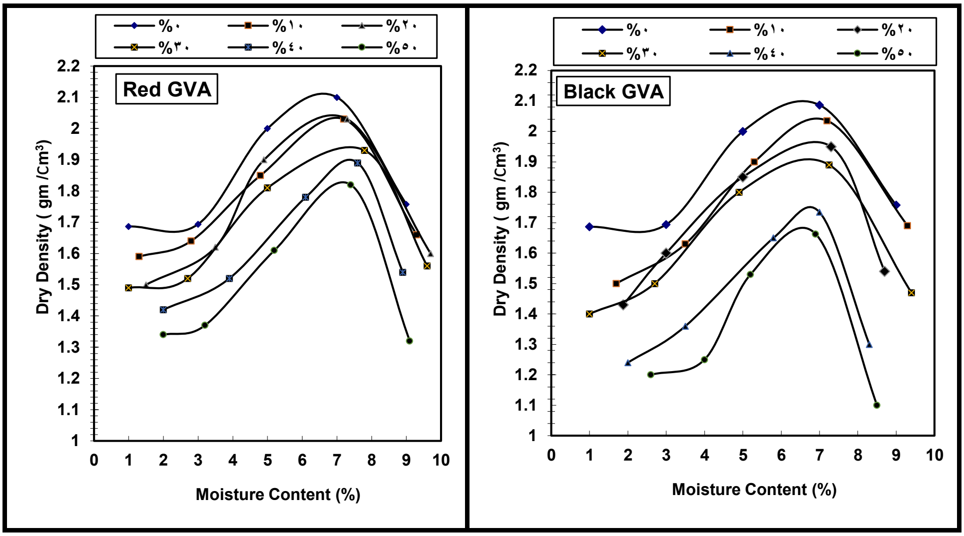

Figure 4: Compaction characteristics of base-GVA mixtures

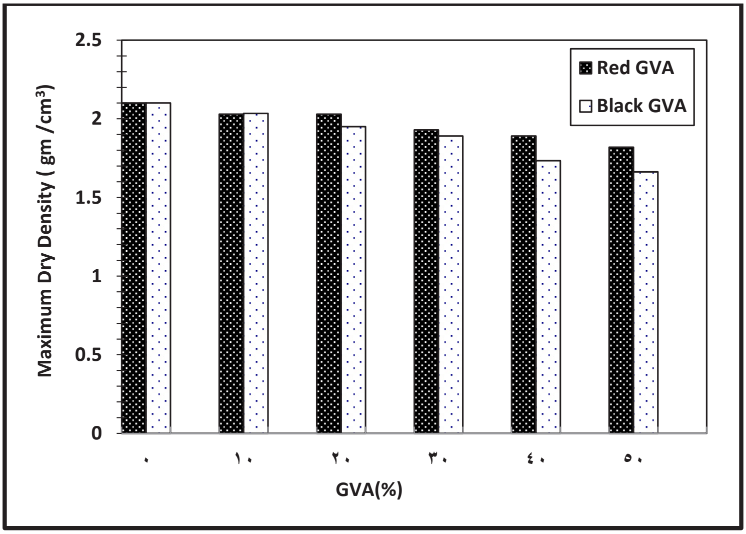

Figure 5: Effect of GVA content on the maximum dry density of the mixes

4.2. Effect of volcanic ash content on value of CBR of the mixes

For the required mixes, dried basalt aggregate and GVA materials have been blended in is required proportions, compacted in the CBR molds to their maximum dry densities, and then soaked for four days. After the required soaking period had finished, the samples were tested in the CBR test apparatus at a strain rate of 1.25 mm/min in accordance with ASTM D4429 [15]. Figure 6 shows the loading stress-penetration curves at each GVA level.

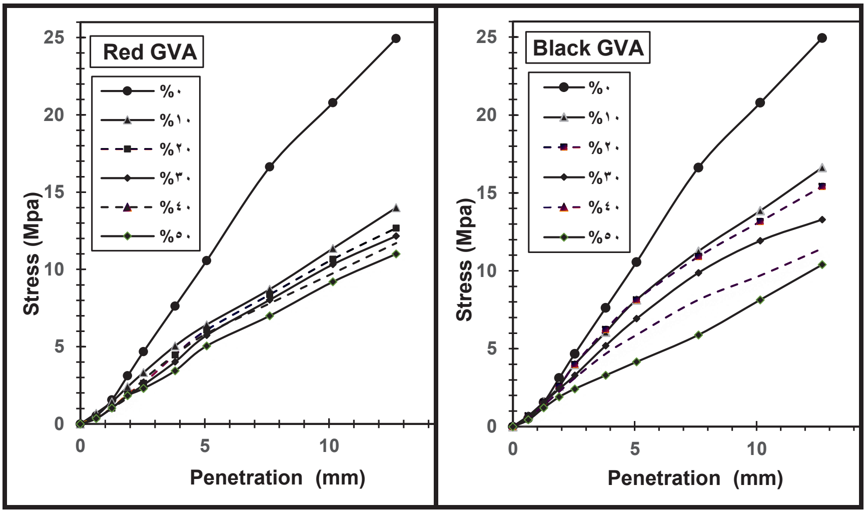

Figure 6: Stress-penetration curve of base-GVA mixtures

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The following identifications were obtained using the CBR analysis data displayed in Figure 7. CBR values have decreased as GVA as a percentage increase; this decrease depends on GVA type. The CBR strength for base-GVA mixtures fulfils the criteria to use as base course materials (CBR value greater than 80) at a GVA content of 10 to 20 % for Black GVA, and 1030%- for Red GVA.

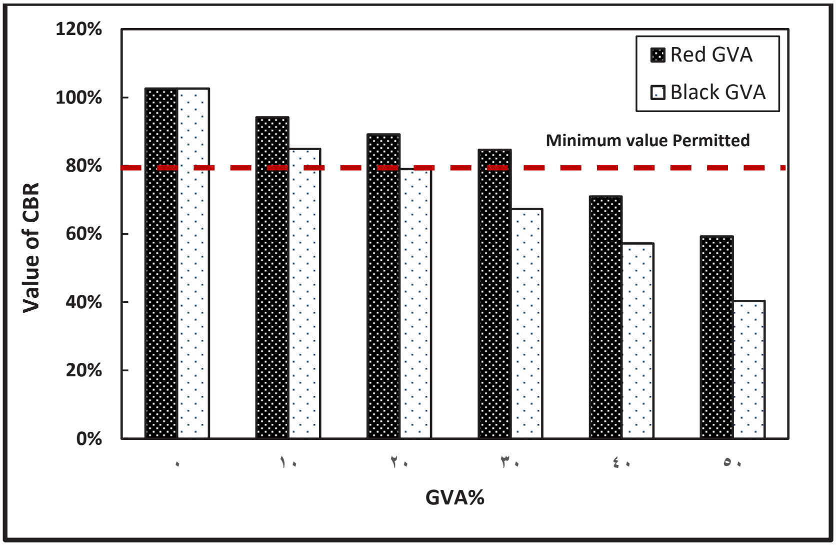

Figure 7: Effect of GVA content on values of CBR of the mixes

4.3. Effect of volcanic ash content on abrasion of the mixes

For base materials with GVA, Figure 8 shows the values for Los Angeles abrasion. It indicates that when the GVA % increases, abrasion values increase. At the same GVA %, it can be shown that the value of abrasion is higher in base-black GVA mixtures than base-red GVA materials. This difference is caused by the varied specific gravities (densities) of the various GVA materials. Base materials` abrasion values must not exceed 40% in order for them to be used in the construction of pavement. Therefore, base materials with 40% Black-GVA or 50% Red-GVA fulfill this requirement, due to, base-GVA materials with these values will result in abrasion values of 34% and 38%, respectively.

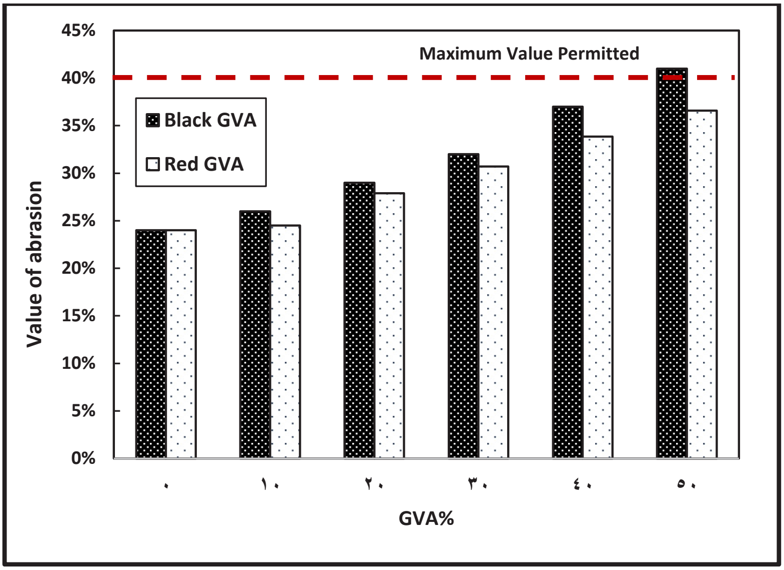

Figure 8: Effect of GVA content on values of abrasion of the mixes

4.4. Effect of volcanic ash content on permeability of the mixes

Permeability of base materials when combined with GVA is shown in Figure 9. GVA can improve the permeability of layers when added to base materials. As was explained earlier, an increase in GVA percentage in the base material results in a decrease in the mixture`s density and an increase in the void ratio, which leads to an increase in permeability. This increase in water flow is a result of the base-GVA mixture`s increasing porosity, similar result found by [17]. Permeable materials such as GVA are needed used in construction to overcome the problems of wetting, and pressure buildup in pavement layers.

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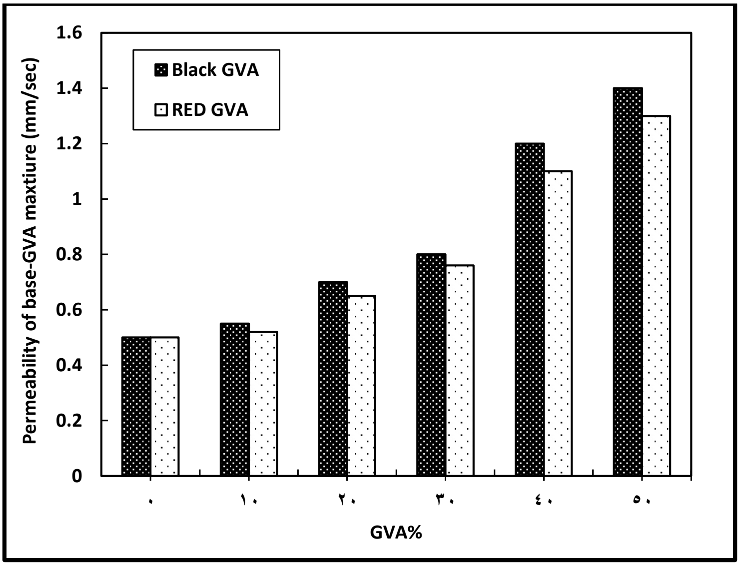

Figure 9: Effect of GVA content on permeability of the mixes

5. Conclusions

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

- The maximum dry density and California bearing ration (CBR %) of base-GVA mixture was decreased with the increasing of GVA% for both GVA type. The CBR strength for base- GVA mixtures fulfils the criteria to use as base course materials at a GVA content of 10- 20 % for Black GVA, and 10-30% for Red GVA.
- The abrasion % and permeability coefficient of base-GVA mixture increased with increasing the GVA content for both GAV types.
- Base-Red GVA mixture fulfils the abrasion % criteria at a GVA content of 10-40%, where Base-Black GVA mixture fulfils this criterion at a GVA content of 10-30%. This is might be because of the specific gravity of the particles of Red GVA are larger than Black GVA.
- In order to estimate the maximum GVA content for base-GVA mixture to use as base course materials, the maximum content of the two criteria (CBR and Abrasion) need to be considered. Therefore, the maximum GVA content for both types is 20%.

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