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RESEARCH ARTICLE **ROAD AND TRANSPORTION ENGINEERING**

Comparative Study of Physical and Mechanical Properties of Base Course Materials from 3 Different Gravel Pits within the Municipality of Brack Alshatti, Libya

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A B S T R A C T

Base course layer is an essential element of the geometry of roadways. Its quality and performance can directly influence the durability and safety of roadways. Problems encountered in roadways such as rutting, surface deformation, water infiltration, resistant to traffic load can be linked to inefficient construction of one or more roadways elements amongst which can be selection of poor base course materials leading to less durable pavement, lower service capacity, and threatening the safety and serviceability of the roadways. There is a crucial need for defining the best base course source within the municipality of Brak Al-Shatti for usage in construction and maintenance of roadways in the region. This study presents a comparative analysis of physical and mechanical properties of three base course material obtained from three different aggregate producers namely Rwawas Company, Al-jebal Al-Afreqiya Company, and Al-Moatamed Alawal Company. The ranking of tested base course materials was based on the results of an experimental program used for base course examination including grain size distribution, maximum dry density, strength, and other physical and mechanical parameters. The results confirm the superiority of the base course materials produced by Al-Moatamed Alawal Company (denoted as BC3 in this study) followed by the base course materials produced by Rwawas Company (denoted as BC1 in this study) and lastly the base course materials produced by Al-jebal Afreqiya Company (denoted as BC2 in this study).

دراسة مقارنة للخواص الفيزيائية والميكانيكية لمواد الأساس الحبيبي من 3 معامل مختلفة لصناعة الحصى في بلدية براك الشاطئ، ليبيا.

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الكلمات المفتاحية

إنشاء الطرق
طبقة الأساس الحبيبي
متانة طبقة الأساس الحبيبي
التوزيع الحبيبي لطبقة الاساس
الدمك لطبقة الأساس الحبيبي
نسبة تحمل كاليفورنيا
الكثافة الجافة القصوي
محتوى الرطوبة الأمثل

الملخص

تعتبر طبقة الأساس الحبيبي عنصراً أساسياً من العناصر الهندسية المكونة لجسم الطرق. يمكن أن تؤثر جودتها وأدائها بشكل مباشر على متانة الطرق وسلامتها. يمكن أن يكون سبب المشاكل التي تواجهها الطرق مثل التصدعات وتشوه السطح وتسرب المياه ومقاومة أحمال المرور ناتج من استخدام مواد طبقة أساس حبيبي رديئة الجودة مما يؤدي إلى رصف أقل متانة ويقلل من القدرة الاستيعابية للطرق ويهدد سلامة الطرق وقابليتها للخدمة. هناك حاجة ماسة لتحديد أفضل مصدر لطبقة الأساس الحبيبي داخل بلدية براك الشاطئ للاستخدام في بناء وصيانة الطرق في المنطقة. تقدم هذه الدراسة تحليل مقارنًة للخصائص الفيزيائية والميكانيكية لثلاث مواد أساس حبيبي تم الحصول عليها من ثلاث شركات مختلفة منتجة لمادة الأساس الحبيبي وهي شركة رواوص وشركة الجبال الأفريقية وشركة المعتمد الاول. تم تصنيف مواد طبقة الأساس الحبيبي المختبرة في هذه الدراسة بناءً على نتائج التجارب المعملية التي تم اجراؤها علي مواد الأساس الحبيبي بما في ذلك التوزيع الحجمي لحبيبات مادة الأساس الحبيبي، الكثافة الجافة القصوى، المتانة، ومعلمات فيزيائية وميكانيكية إخرى. تؤكد النتائج تفوق مادة الأساس الحبيبي التي تنتجها شركة المعتمد الاول (المشار إليها في هذه الدراسة بـ BC3) تليها مادة الأساس الحبيبي التي تنتجها شركة رواوص (المشار إليها في هذه الدراسة بـ BC1) وأخيراً مادة الأساس الحبيبي التي تنتجها شركة الجبال الأفريقية (المشار إليها في هذه الدراسة بـ BC2).

Introduction

Roadway paving serves multiple purposes, including providing a surface for traffic, supporting traffic loads, and guiding surface water into the drainage system for removal. Materials vary in the extent to which they exhibit these characteristics, which is why base and surface courses are separately constructed, even though they form a cohesive unit.

The base course, placed atop the sub-base, provides support to the surface course and transfers traffic loads onto the subgrade. The thickness of the base course varies based on the design load and the material's characteristics. The completed base may consist of more than one layer, separately placed and compacted. For any base course or surface course to perform effectively, it requires sufficient support from the underlying sub-base and sub-grade. The sub-base must maintain the correct line, grade, cross-sectional shape, and compaction. If there are defects or damage in the sub-grade or sub-base, it will risk the stability and serviceability of the base course and surface layer directly.

The base course is the structural component of the flexible pavement which adds to its stability. The base course directly receives the traffic loads from the wearing surface and has, therefore, to be strong enough to resist the effects of loading and weather. The minimum prescribed California Bearing

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Ratio (CBR) is 80% for stability and prevention of water soaking through the base. It has to be as dense material as possible.

Generally, crushed stone or water-bound macadam is recommended for base courses. However, using a stabilizing agent like cement, soil-aggregate mixtures or local silty soils in combination with cement, lime, or asphalt stabilization, maybe required in case base course materials available in local pits are not competent enough. Nevertheless, crushed stone or angular bases will remain the primary choice.

The base courses materials are categorized as either dry-bound or water-bound macadam, depending on the construction method. Dry-bound macadam denotes a crushed stone base course that gains its strength by grain-to-grain contact through interlocking by rolling or vibration. In water-bound macadam, water is added after incorporating the fines, and then the entire mass is rolled. In this case, stability is inherited from grain interlock and the cementation of fine fractions. The most common method of base course construction is water-bound macadam (WBM) used an all-in-run aggregate/granular base course, mixed with the fine fraction, at the optimum moisture content (OMC).

Specifications for Base Material

The base course material must meet well-graded aggregates specifications in accordance to AASHTO M-43/ASTM D-448 when tested using laboratory sieves. The designated size must conform to the requirements demonstrated in Table 1. The crushed stone shall consist of clean, tough, durable fragments, free from any excess of flat, elongated, soft, and disintegrated pieces. Shale, phyllite, slate, or schist shall not be used as base course material due to their tendency to produce excessively elongated particles. The screenings shall be of suitable binding quality and conform to the sizes mentioned.

Table 1: Base course graduation according to AASHTO M-43/ASTM D-448 [8]

Sieve size (mm)	Percent finer by weight (%)	
	UPPER LIMIT	LOWER LIMIT
50	100	100
25	95	75
9.5	75	40
4.75	60	30
2	45	20
0.425	30	15
0.075	15	5

The crushed stone must meet the limits and specifications listed in Table 2.

Table 2: Specification of Base course materials

Sr. No.	Test Property	Specified limits
1	Los Angeles Abrasion value % (Max)	40
2	Bitumen Adhesion % (Max) for top layer	Above 95
3	Flakiness and Elongation (BS-812) (Max)	35%
4	Soundness % (Max)	12%
5	Water Absorption % (Max)	2

General Construction Base Course Material

The base course is crucial for load bearing in highway and road construction. The durability and ride quality of the surface depend on its construction quality. It can constitute either a single layer or multiple layers added above the sub-base, sometimes incorporating additional materials mixed into the upper sub-base to a specific depth.

Depending upon the traffic load and quality of sub-grade materials, sub-base layer maybe required before placing the base course layer. The sub-base shall be prepared for the full base width as specified on the design plans. It should be thoroughly compacted and constructed to match the alignment and grade indicated on the design plans. The grade of the base course layer must be controlled with fixed control stakes not to exceed 25 feet longitudinal spacing and 25 feet transverse spacing. The top lift of any base course must not deviate more than 3/8 inch from the grade established. The Inspector should carefully attend to achieving a uniform surface on each layer as they are being constructed. The Inspector must ensure the correct crown is in place where required and prevent any longitudinal waves from appearing on any course.

The compacted thickness of any layer of the base course should not be less than 3 inches and more than 6 inches when using smooth wheel roller but with vibratory compactors a compacted thickness of the layer can be up to 8 inches. The thickness of the compacted layer should not exceed 4% (1⁄2 inches). If the contractor can satisfactorily demonstrate the ability to achieve compaction in a 6-inch-thick layer using specialized rolling equipment, they may receive permission to do so from the engineer.

Quality of constriction of base course layer depends on the input parameters defined through laboratory tests including optimum moisture content (OMC), compaction efficiency, Grain Size Distribution (GSD), Maximum dry density (MDD), and Aggregate toughness and abrasion resistance, fine and coarse aggregate absorption to water. Failure to meet the design specifications of any of these factors could result in low-quality base course layer, thus, risks the stability, durability, and safety of the roadway. The following sub-sections highlight the influence of abovementioned input parameters on the performance of base course layer.

Moisture Content (MC)

Understanding the effects of moisture on base course performance is vital for effective pavement design and maintenance. Benson & Trast, (2000) stated that increased moisture content can reduce effective stress, leading to a decrease in cohesion and friction angle and overall strength due to pore pressure buildup. This may cause a higher likelihood of rutting and deformation under traffic loads. Insufficient moisture, on the other hand, can lead to inadequate compaction (AASHTO, 1993). Ensuring optimal moisture content (OMC) would facilitate achieving the maximum dry density and efficient compaction. According to Gubler & Scherler, (2010), Moisture content can affect California Bearing Ratio (CBR), where increased moisture levels generally lead to reduced CBR values, indicating lower strength. Excess moisture content can also contribute to the erosion of base materials, especially under repeated loading and wet-dry cycles, leading to compromising integrity of the pavement structure over time [1].

Compaction

Compaction is another critical process in the construction of pavement base courses, significantly influencing their mechanical properties and overall performance. Optimal compaction increases the density of the base material, which enhances its strength and load-bearing capacity. The California Bearing Ratio (CBR) is often used to evaluate this effect, where higher compaction levels generally correlate with improved CBR values [2]. Studies conducted by [3] have shown that optimal compaction led to increased CBR by up to 50% compared to poorly compacted materials. Proper compaction enhances stiffness modulus of the base course leading to reduced voids in the material skeleton, reduced risk of permanent deformation and cracking, which ultimately helps distributing traffic loads more effectively [1]. Reduced void spaces inherited from proper compaction would, furthermore, decrease the likelihood of erosion and material degradation over time [4]. Optimal compaction would also lead to denser base course materials and higher inter-particle friction, where both can result to improvement of resistance to shear forces [5]. This is particularly important in preventing rutting and lateral displacement under repeated traffic loads. In general, well-compacted materials are less prone to water infiltration and subsequent erosion, thus enhancing the longevity of the pavement structure [6].

Grain Size Distribution (GSD)

Another important key-performance parameter is the grain size distribution (GSD) of the base course materials. The arrangement and size of particles affect the compaction behavior, strength, drainage capabilities, and resilience of the base material. Well-graded materials, which contain a range of particle sizes, typically achieve higher densities during compaction than poorly graded materials. This is because smaller particles fill the voids between larger particles, maximizing density [2]. Studies indicate that a well-graded aggregate can improve compaction efficiency by up to 30% compared to uniform aggregates [3]. The load-bearing capacity of base courses is closely related to GSD. Coarse-grained materials tend to have higher shear strength due to larger particle interlocking, while well-graded mixtures combine the benefits of both coarse and fine materials to achieve optimal strength [1]. Research works conducted by [5] show that optimal GSD can lead to a 20-50% increase in California Bearing Ratio (CBR) values compared to poorly graded materials The permeability of base courses is influenced by GSD, where well-graded materials often provide better drainage, reducing the potential for water retention and associated problems like erosion and instability [4]. Grain size distribution affects the durability of base courses against environmental factors. Materials with a wide range of particle sizes tend to be denser and have more resistant to water infiltration [3,6]. This resistance is crucial for maintaining the structural integrity of pavement over time. The performance of base courses under repeated loading is also influenced by GSD. Well-graded aggregates provide better inter-particle contact, enhancing resistance to deformation and rutting under traffic loads. Poorly graded materials are more susceptible to shear failure and deformation [5].

Maximum Dry Density (NDD)

Maximum dry density (MDD) is a critical parameter in pavement engineering, affecting the strength, stability, and overall performance of base courses. MDD is influenced by the material's moisture content during compaction and plays a significant role in determining the pavement's ability to support loads. Compacted materials that achieve their MDD exhibit superior California Bearing Ratio (CBR) [2]. Research indicates that each 1% increase in density can lead to a corresponding increase in CBR by approximately 5% [3]. A base course with high MDD is more resistant to deformation under traffic loads. Materials with optimal compaction achieve better particle interlock and cohesion, minimizing rutting and permanent deformation [1].

Higher MDD often results in reduced void spaces within the base course, improving moisture resistance. This characteristic is crucial for mitigating issues related to water infiltration, which can weaken the pavement structure over time (Benson & Trast, 2001). Effective moisture management helps maintain the integrity of the base course under varying environmental conditions, thus, enhancing durability of base courses against environmental stresses from wet-dry cycles and freeze-thaw cycles (NCHRP Report 371).

Resistant to abrasion

Resistant to abrasion is another key performance parameter important to the coarse portion aggregate forming base course layer. Tough aggregates can better resist fracture under load, leading to enhanced load-bearing capacity. Higher toughness can generally improve CBR values by up to 30% compared to softer materials (AASHTO, 1993). Abrasion-resistant aggregates reduce the potential for wear and deformation in the base course. Materials with high abrasion resistance maintain their shape and size under repeated loading, minimizing rutting and surface deformation [3]. This is valuable for maintaining the structural integrity of pavements over time. Tough and abrasion-resistant aggregates are less susceptible to degradation from environmental factors such as freeze-thaw cycles and moisture infiltration. Studies show that aggregates with high toughness maintain their physical properties better than weaker aggregates in harsh conditions [1]. This durability contributes to the longevity of the pavement. Tougher aggregates typically provide better interlocking and particle cohesion, facilitating optimal compaction and higher density [5]. This leads to improved overall performance of the base course. Aggregates that resist wear help maintain surface texture and friction, reducing the likelihood of surface failure and enhancing safety [4]. Proper selection of aggregates based on toughness and abrasion resistance is essential for high-traffic pavements.

Problem Statement

In the recent years, the municipality of Brak Al-Shatti witnessed multi-scale projects of rehabilitation and reconstruction under the national plan of municipalities' rehabilitation and reconstruction. Maintenance projects of roadways were not exception, where many roadways within and around the municipality of Brak Al-Shatti have been defined in the plan for maintenance and rehabilitation. This, simultaneously, led to huge demand on base course materials as part of roadway geometry. The demand has been mainly supplied by three aggregate pits in the area namely Rwawas Company, Al-jebal Al-Afreqiya Company, and Al-Moatamed Alawal Company. Projects owners often require the contractors to provide test certificates of the base course materials they want to use for a specific project, which often is costly and time consuming. This paper is aimed at setting a comparative analysis between the physical and mechanical properties of the base course materials from these three pits to provide a comprehensive report that can be a reference for decision makers to select the most efficient base course materials based on the predefined projects-specific needs.

Evaluation Approach

Methodology adopted for this research work is based on experimental program through which the physical and mechanical properties of the base course materials are determined. The experimental program included defining the following [7-10]

1- Grain size distribution via sieve analysis and hydrometer tests according to ASTM D422.
1. Specific gravity and percent of absorption according to ASTM C 127.

2. Consistency limits of the fine portion for determining plastic and liquid limits, if required, according to ASTM D4318-17e1.
3. Resistance to abrasion of the coarse portion of the aggregates according to ASTM C 131.
4. Maximum dry density and optimum moisture content via modified proctor test according to ASTM D1557.
5. California bearing ratio (CBR) test according to ASTM D1883-21.

These tests are conducted for the base course materials from the three pits such that comparison evaluation among each other and with standards and specifications can be attained.

Materials

Base course materials for the experimental program have been obtained from the three above-mentioned pits with enough quantities that allow obtaining the key-performance parameters from the selected laboratory tests. the geographic locations of the three pits are as follows:

- Rawaws base course materials, denoted as BC1 in this report, is produced in the mountain of city of Mahrogha that is located 35 km to the west of Brak Al-Shatti on the northside of Brak-Edri highway
- Al-jebal Al-Afreqiya base course materials denoted as BC2 in this report, is produced in in the city of Gera and located 40 km to the north of Brak Al-Shatti on the east side of Sebha-Tripoli highway.
- Al-Moatamed Alawal base course materials denoted as BC3 in this report, is produced in the agriculture project of Gelan and located 180 km to the north of Brak Al-Shatti on the west side of Sebha-Tripoli highway.

Location of the three pits can be more recognized by looking at Figure 1 from Google map.

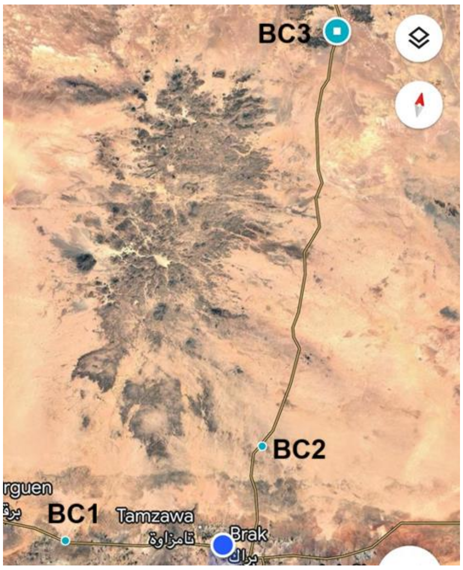
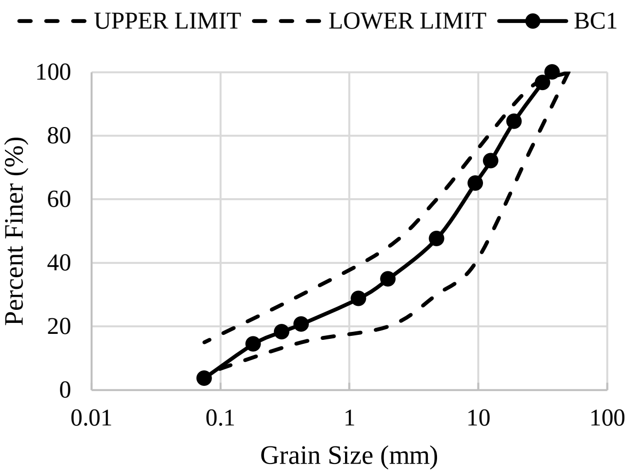


Fig.1: location of the three gravel pits from the satellite

Results and discussion

Result of grain size distribution (GSD) obtained from sieve analysis for BC1, BC2, and BC3 are shown in Figures 2, 3 & 4 respectively. The upper and lower limits for GSD of base course martial according to ASTM standard are also shown on the graph with the dashed lines. The GSD of BC1 and BC3 exhibited better fit to standard limits than BC2.



Fig,2: Grain Size Distribution for BC1

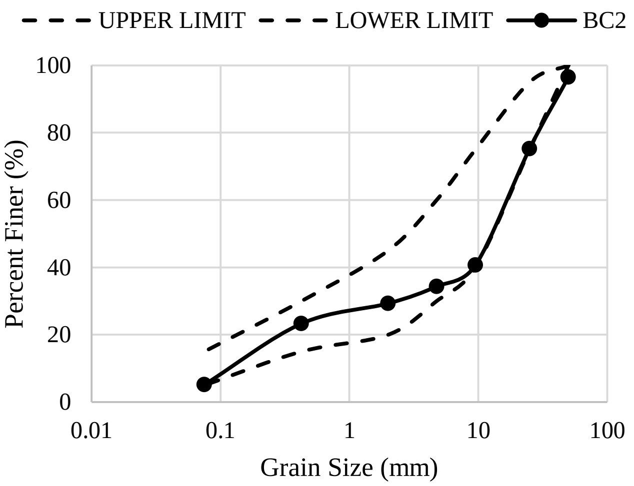


Fig.3: Grain Size Distribution for BC2

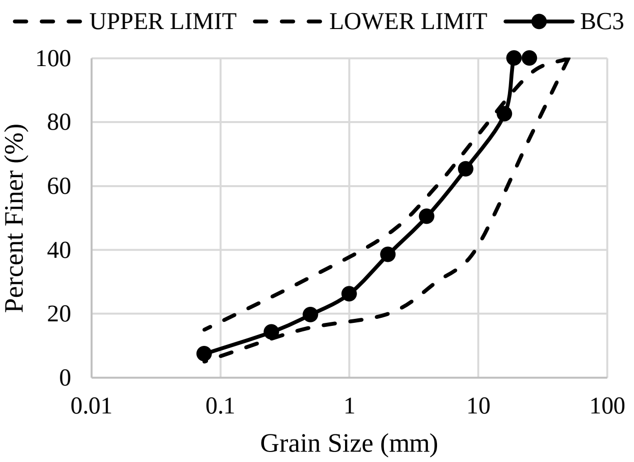


Fig.4: Grain Size Distribution for BC3

Table 3 demonstrates the coefficient of uniformity, coefficient of curvature (also know as coefficient of graduation), soil classification based on ASTM's unified classification system, and quantities of different grain size. BC1 and BC3 show even distributions of gravel and sand contents which result in good graduation compared to BC2 that exhibits uniform grain size with higher gravel content and lower sand content. The predominant uniform graduation for BC2 can be further confirmed from its value of coefficient of uniformity (Cu) that was higher for BC2 recording 71.3 and lower for BC1 and BC3 recording 57.1 and 50.0 respectively. The good grain size distribution for BC1 and BC3 is evident from coefficient of graduation (Cc) perspective, which is higher for BC1 and BC3, recording 1.5 and 2.3 respectively, and lower for BC2 recording 0.8. Amongst all, BC3 has the highest value of coefficient of graduation (Cc) indicating the best grain size distribution. Based on these parameters, BC1 and BC3 are classified as well-graded gravel (GW) while BC2 is classified as poorly graded gravel (GP) as per the ASTM unified classification system. Soil materials with well-graduation will often show higher maxim dry density (MDD) due to the varieties of grain size present where smaller particles will fill the voids between the larger particle size leading to less void space. Therefore, BC3 can be considered superior among the other base course materials considered in this study based on GSD, followed by BC1 and BC2 respectively

Table 3. Classification of three base course materials

Sample	**BC1**	**BC2**	**BC3**
D30	8.0	10.7	6.5
D60	1.3	1.1	1.4
D10	0.1	0.2	0.1
Cu	57.1	71.3	50.0
Cc	1.5	0.8	2.3
% Gravel	52.43	65.67	49.52
% Coarse sand	26.86	11.03	30.78
% Fine sand	17.00	18.16	12.29
% Silt and clay	3.70	5.14	7.41
UCS	GW	GP	GW

The results of maximum dry density (MDD) indicates that BC3 has the highest MDD exhibiting 2400 kg/m3 followed by BC1 with MDD equal to 2182 kg/m3 and BC2 with MDD equal to 2055 kg/m3 as shown of Figure 5, 6, &7. On the same figures, the optimum moisture content (OMC) is estimated as 6.5% for BC1, 8.5% for BC2, and 6.3 for BC3 where the BC material with higher MDD showed lower OMC. This can be attributed to the lower void available for moisture for BC materials with higher MDD.

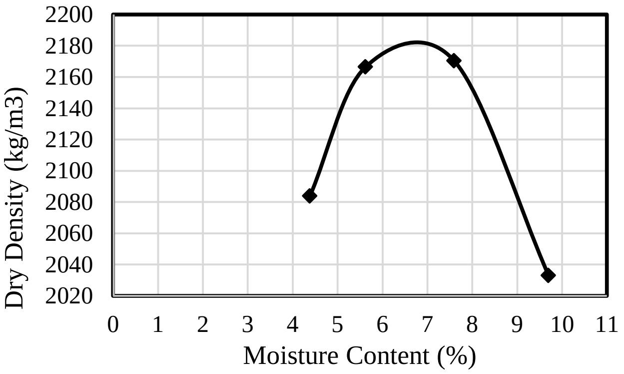


Fig.5: Results of modified Proctor Test for BC1

The strength of BC materials can be inferred from the results of California Bearing Ration (CBR) which are summarized in figure 8, 9 and 10. The tests were performed for unsoaked condition. The curves were corrected for concave upwards that often resulted from surface irregularities of the test sample at the onset of the test. The corrected initial penetration was found to start at 0.5 mm for BC1, 0.45 mm for BC2, and 0.4 mm for BC3.

Table 4 summarized the CBR value at penetration of 2.5 mm after correction for the three base course sample. For the seek of comparison, CBR values were determined at a penetration value of 2.5 mm only. The standards and specifications highlighted in ASTM D1883 indicates that CBR value for base course materials shall not be less than 80%. This condition was met for BC1 and BC3 recording 82.86% and 144.29%, while BC2 failed to meet the specification with CBR value equal to 28.57%. The highest CBR value for BC3 aligns with its highest MDD, lowest OMC, and best GSD and vise versa for BC2. The test results of CBR test, therefore, support the previous observations that BC3 is still superior among the tested BCs in exam.

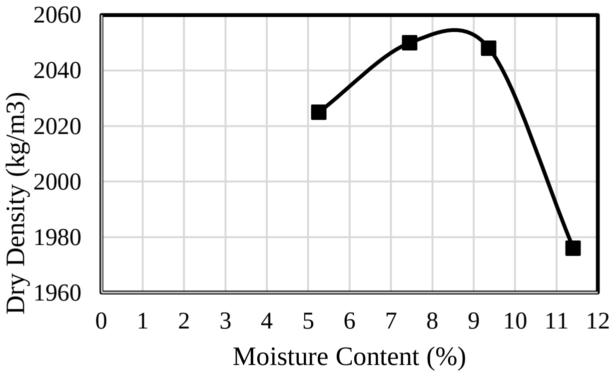


Fig.6: Results of modified Proctor Test for BC2

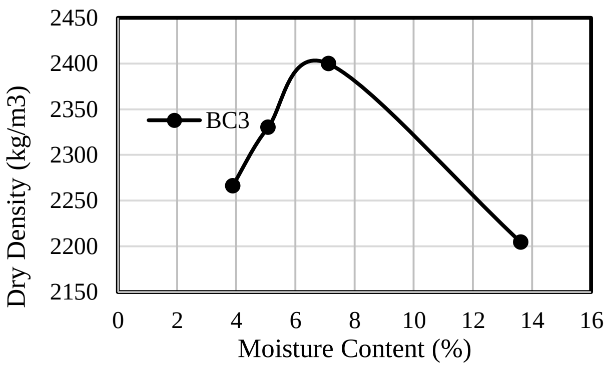


Fig.7: Results of modified Proctor Test for BC3

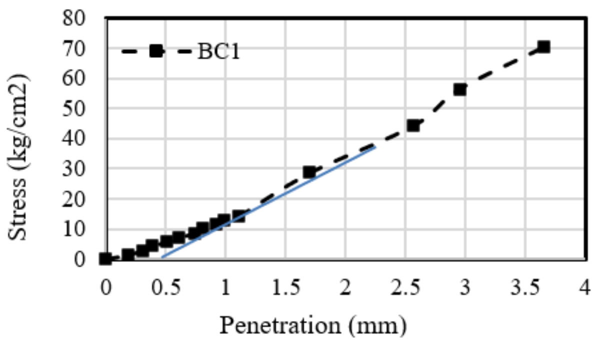


Fig.8: Results of CBR for BC1

Results of specific gravity, percent of absorption, and resistance to abrasion are summarized in Table 5. BC3 has shown the highest resistance to abrasion, highest specific gravity and lowest water absorption. It was followed by BC1 and at the bottom rank was BC2. This again aligns with results from all previous test that confirm the superiority of BC3 as a base course material compared to BC1 and BC2.

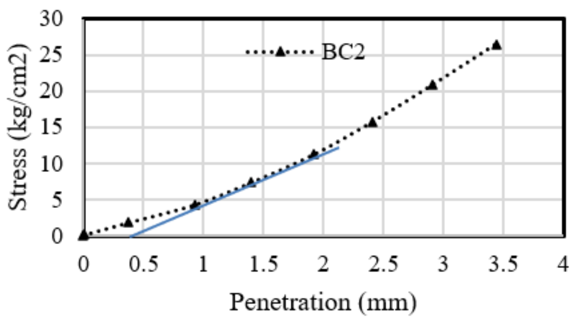


Fig.9: Results of CBR for BC2

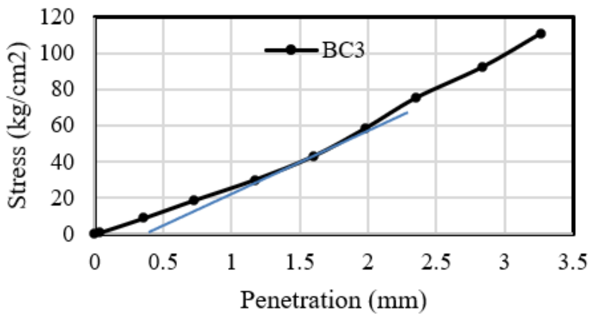


Fig.10: Results of CBR for BC3

Table 4: Results of CBR at penetration of 2.5 mm

Sample	Penetration	Stress @ Corrected Penetration (mm)	STD. Stress @ 2.5 mm	CBR
#	(mm)	(kg/cm2)	(kg/cm2)	(%)
BC1	3.00	58	70	82.86
BC2	2.95	20	70	28.57
BC3	2.90	101	70	144.29

Table 5: some of mechanical and physical properties of tested base course materials

Test Property	Specified limits			
	BC1	**BC2**	**BC3**	**Standards**
Los Angeles Abrasion value %	19.44	39.12	16.25	40
Specific Gravity	2.71	2.69	2.720	No limits
Water Absorption % (Max)	2.35	3.42	2.01	2

Conclusion

A comparative study was conducted on three base course materials produced in three different aggregate pits within the municipality of Brack Alshatti. The study aims at determining the best base course materials for use in construction and maintenance of roadways in the region for enhancing durability and safety of roadways. Based on the experimental work conducted and results obtained, the following conclusions can be drawn:

1- Base course materials produced in Al-Moatamed Alawal aggregate pit (BC3) showed the best fit to the standards and specifications of grain size disruption highlighted in AASHTO M-43 and ASTM D-448.
2- BC3 also had the highest maximum dry density and lowest optimum moisture content compared to base course materials produced in Rawaws aggregate pit (BC1) and base course materials produced in Al-jebal Al-Afreqiya aggregate pit (BC2).
3- BC3 was stronger by demonstrating the highest CBR followed by BC1 and BC3.
4- BC3 had the highest resistance to abrasion, highest specific gravity and lowest water absorption.
5- For more durable and safer roadways, BC3 is recommended first for base course materials followed by BC1 and last BC2 based on the results of study.

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Conflicts of Interest: "The authors declare that they have no conflict of interest."

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