Wadi Alshatti University Journal of Pure and Applied Sciences

مجلة جامعة وادي الشاطئ للعلوم البحتة والتطبيقية

Volume 3, No. 2, July-December 2025 Online ISSN: 3006-0877 المجلد 3، الاصدار 2، يوليو - ديسمبر 2025

RESEARCH ARTICLE **CIVIL ENGINEERING**

Study and Comparison of Physical and Mechanical Properties of Highway Base Layer Materials from Different Sources

Hassan Awadat Salem[1*]

[1]Civil Engineering Department, Faculty of Engineering, Wadi Alshatti University, Brack, Libya

ARTICLE HISTORY

Received 24 May 2025
Revised 15 July 2025
Accepted 20 July 2025
Online 27 July 2025

KEYWORDS

Base course physical and chemical testing;
Base layers;
Specifications.

ABSTRACT

The construction of durable and safe highway infrastructure relies heavily on the mechanical properties of base course materials, such as strength and gradation. This study investigates base course materials from five different sources, aiming to evaluate their physical and mechanical properties. Laboratory tests, including sieve analysis, liquid and plastic limits, Proctor compaction, California Bearing Ratio (CBR), and Los Angeles abrasion tests, were conducted following ASTM standards. Results revealed significant differences among the samples: four samples met ASTM specification limits, with Los Angeles abrasion values ranging from 17.2% to 49.3% and CBR values between 75.6% and 182.8%. One sample failed to meet the grading and CBR criteria. These findings underscore the importance of thorough material testing to ensure road stability and longevity.

دراسة ومقارنة الخصائص الفيزيائية والميكانيكية لمواد طبقة الاساس الحبيبي للطرق من مصادر مختلفة

حسن عويدات سالم[1]

الكلمات المفتاحية

اختبارات المواد الفيزيائية والكيميائية للط الأساسية
الطبقات الأساسية
المواصفات

الملخص

يعتمد بناء بنية تحتية دائمة وآمنة للطرق السريعة بشكل كبير على الخصائص الميكانيكية لمواد الطبقة الأساسية، مثل القوة والتدرج .تهدف هذه الدراسة إلى تقييم الخصائص الفيزيائية والميكانيكية لمواد الطبقة الأساسية من خمسة مصادر مختلفة . تم إجراء اختبارات معملية تشمل تحليل الغربال، حدود السيولة واللدونة، اختبار بروكتور، نسبة تحمل كاليفورنيا (CBR)، واختبار التآكل لوس أنجلوس، وفقًا لمعايير ASTM. أظهرت النتائج وجود اختلافات كبيرة بين العينات :أربع عينات استوفت حدود مواصفات ASTM، حيث تراوحت قيم التآكل لوس أنجلوس بين 17.2% و49.3%، وقيم CBR بين 75.6% و182.8%. في المقابل، فشلت عينة واحدة في تحقيق معايير التدرج و CBR. تؤكد هذه النتائج على أهمية إجراء اختبارات دقيقة للمواد لضمان استقرار الطرق وطول عمرها.

Introduction

The base layer forms the foundation for the road surface and is critical for distributing traffic loads to prevent deformation of the subgrade. The bottom layer comprises an unbound mixture of coarse and fine crushed stone, as well as crushed sand, to achieve the desired load-bearing capacity and absorb traffic loads efficiently [1]. This layer allows adequate subsurface drainage, which is essential for maintaining road performance over time [2-8].

The base course is typically constructed using high-quality gravel or crushed aggregate. When heavy traffic is anticipated, the base course often consists of Hot Mix Asphalt (HMA) to enhance durability. Base courses provide the necessary thickness to ensure that the road surface can withstand traffic loads during its service life, with typical thicknesses ranging from 100 to 300 mm, depending on traffic load requirements [9]. A thicker base course is generally required to accommodate heavier loads and reduce surface stress, mitigating fatigue cracking.

Base course mixes are traditionally designed with larger aggregate sizes compared to surface course mixes. Maximum aggregate sizes for base courses typically range between 19 and 37.5 mm, creating a lean mix with lower asphalt binder content, which helps reduce costs [10].

The construction and performance of flexible pavements rely heavily on the quality of base course materials. Research highlights that the base course serves as a critical layer for distributing traffic loads, ensuring stability, and facilitating drainage. Materials used for base courses must adhere to stringent specifications, such as those outlined by ASTM D1241 [11], to meet the demands of heavy traffic and environmental stresses [12,13]

Despite the established standards, there remains significant variability in the properties of materials from different sources, as noted by [8]. This variability can impact the performance

*Corresponding author
https://doi.org/10.63318/waujpasv3i2_19

and longevity of pavements, particularly in regions with diverse geological conditions. Recent studies by Ghabchi et al. emphasize that gradation, compaction, and strength characteristics are key parameters influencing the performance of aggregate bases [1].

Additionally, advances in testing methodologies have revealed gaps in the understanding of material behavior under traffic loads. For example, Jayawickrama et al [14,15] highlighted the need for more robust evaluation techniques to capture the mechanical behavior of base and subbase layers. Similarly, Ozturk and Yuksel [16,17] stressed the importance of proper gradation in enhancing the durability and stability of base course materials.

Sustainability in pavement materials is also an emerging area of interest. Research by Huang and Xu [18] explores the use of recycled aggregates in base layers, offering a potential solution to resource scarcity while maintaining performance. However, the integration of such materials requires further validation through field studies.

This study addresses the gap in the domain knowledge by focusing on the variability of base course materials from different sources and their compliance with ASTM [8] and AASHTO specifications [19]. While previous research has provided a foundation, there is limited exploration of the combined effects of gradation, strength, and plasticity on material performance across varied sources. By conducting a comprehensive laboratory evaluation, this study aims to bridge this gap and provide actionable insights for the selection and preparation of base course materials.

Functions of the Base Course:

1. **Load Distribution:** The primary function of the base course is to evenly distribute the pavement surface loads to the subgrade, preventing excessive stress and deformation.
2. **Stability and Support:** The base course provides a stable platform for pavement layers, preventing the intermixing of subgrade soil and pavement material, thereby maintaining the structural integrity of the road.
3. **Drainage:** A well-designed base course facilitates drainage, preventing water accumulation that could weaken the pavement structure. Effective drainage is crucial in colder climates to avoid frost heave and ensure the road's longevity [1].

The base course mix must meet the gradation specification limits set forth in ASTM D1241 [11] to ensure its effectiveness and durability.

Table (1) provides Details of Gradation Requirements for Soil-Aggregate Materials. According to ASTM standards, the soil classification should be a good foundation Gw, Gp, Gw-Gm, Gw-Gc. According to AASHTO standards, it should meet the specification limits specified as A-1-a, A-1-b. Table 2 tells the soil classification criteria according to the AASHTO (American Association of State Highway and Transportation Officials) standards. This classification system is used to categorize soils based on their granular composition, liquid limit, and plasticity index.

These limits include the California Bearing Ratio (CBR), Los Angeles Abrasion Value, liquid limit, plastic limit, plasticity index, and other properties such as clay lumps, friable particles, and sand equivalent value. The table also indicates the corresponding testing methods (e.g., ASTM and AASHTO standards) used to evaluate these properties. Adherence to these limits ensures that the base course materials can withstand traffic loads, resist abrasion, and maintain stability over time.

Table 1: Gradation requirements for soil-aggregate materials

Sieve size (Square openings)	Weight percent passing square mesh sieves					
	Type I				Type II	
	Gradation A	Gradation B	Gradation C	Gradation D	Gradation E	Gradation F
2-in. (50,0-mm)	100	100	-	-	-	-
1-in. (25.0-mm)	-	75 to 95	100	100	100	100
3/8-in. (9.5-mm)	30 to 65	40 to 75	50 to 85	60 to 100	-	-
No. 4 (4.75-mm)	25 to 55	30 to 60	25 to 65	50 to 85	55 to 100	70 to 100
No. 10 (2.00-mm)	15 to 40	20 to 45	25 to 50	40 to 70	40 to 100	55 to 100
No. 40 (425-µm)	8 to 20	15 to 30	15 to 30	25 to 45	20 to 50	30 to 70
No. 200 (75-µm)	2 to 8	5 to 15	5 to 15	8 to 15	6 to 15	8 to 15

Table 2: Physical and chemical limits that base course materials must meet to be considered suitable for highway construction.

General Classification		**Granular Materials**						
		(35% or less passing 0.075 mm)						
Group Classification		A-1		A-3	A-2			
		A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7
% Passing	2.00 mm	50 max	-	-	-	-	-	-
	0.425 mm	30 max	50 max	51 min	-	-	-	-
	0.075 mm	15 max	25 max	10 max	35 max	35 max	35 max	35 max
Liquid Limit		-		-	40 max	41 min	40 max	41 min
Plasticity Index		6 max		N.P.	10 max	10 max	11 min	11 min
Usual types of significant constituent materials		Stone fragments gravel and sand		Fine Sand	Silty or clayey gravel and sand			
General rating as subgrade		Excellent to good						

Methodology (Laboratory Testing)

This study employed a series of laboratory tests to evaluate the physical and mechanical properties of base course materials from five sources. All tests were conducted in accordance with ASTM and AASHTO standards to ensure consistency and reliability of results.

1. **Sieve Analysis:** The gradation of base course materials was determined using ASTM D1241. This test ensures the materials meet the particle size distribution requirements for highway construction.
2. **Liquid and Plastic Limits:** The Atterberg limits, including liquid and plastic limits, were evaluated following ASTM D4318. These properties help assess the material's plasticity and suitability for base course applications.
3. **Proctor Compaction Test:** The maximum dry density and optimum moisture content of the materials were determined using AASHTO T180, Method D. These values are essential for achieving adequate compaction and stability of the base layer [9].
4. **California Bearing Ratio (CBR) Test:** The CBR test, performed according to AASHTO T193, was used to measure the strength of the base course materials. This test evaluates the material's ability to withstand applied loads, which is crucial for determining its suitability for highway construction [10].
5. **Los Angeles Abrasion Test:** The abrasion resistance of the materials was assessed using ASTM C131 and AASHTO T96. This test measures the durability of the aggregate under simulated traffic conditions.

   Sand Equivalent Test: The sand equivalent value, which indicates the proportion of sand to clay in the material, was determined using ASTM D2419. Materials with a higher sand equivalent value are less prone to deformation under load [1].
6. **Clay Lumps and Friable Particles Test:** This test was conducted in accordance with ASTM C142 to determine the percentage of weak particles in the aggregate. Materials with minimal clay lumps and friable particles are preferred for base courses.

By following these standardized procedures, the study ensured accurate and reproducible results, providing a reliable basis for evaluating the suitability of the base course materials

Laboratory testing

First, physical and chemical tests were performed on the materials coming from 5 different places. These materials are as follows:Table

- Sample 1 – Mahroga Cursher Plant Base Course
- Sample 2 - AlBartama Cursher Plant Base Course
- Sample 3 – Brak –Ash Shwayrif Road KM: 20+000 Sample Base Course
- Sample 4 – Murzug Granüler Base Course
- Sample 5 – Ghadwa Granüler Base Course

This table presents the results of laboratory tests conducted on base course materials from five different sources. The table includes data on Los Angeles Abrasion Value, liquid limit, plastic limit, sieve analysis, flaky and elongated particles, sand equivalent value, aggregate impact value, clay lumps, maximum dry density, and CBR. The results are compared against the specification limits to determine the suitability of each sample. Four out of the five samples met the required standards, while one sample (Sample 3) failed to meet the grading and CBR criteria. This table highlights the variability in material properties and underscores the importance of thorough testing to ensure compliance with construction standards.

As a result of the physical and chemical tests, samples 1, 2, 4 and 5 met the specification limits.

The Cbr value of the 3rd sample is out of specification and does not meet the grading limits.

Table 5 provides the sieve analysis results for the five base course material samples. The sieve analysis is a critical test that determines the particle size distribution of the aggregates, which directly affects the material's compaction, drainage, and load-bearing capacity. The table shows the percentage of material passing through various sieve sizes (50 mm, 25 mm, 9.5 mm, 4.75 mm, 2.00 mm, 0.425 mm, and 0.075 mm). The gradation of the materials is compared against the ASTM D1241 specifications [11], which define the acceptable range of particle sizes for base course materials. Proper gradation ensures that the material can effectively distribute loads and provide adequate drainage, both of which are essential for the long-term performance of the pavement.

Table 3 provides the physical and chemical limits of the Base Material should be as follows

Property	Specification Limits	Testing Method
CBR %	> 80	AASHTO T 180 Method D
Los Angeles Abrasion Value(%)	< 50	ASTM C 131- AASHTO T 96
Liquid Limit, Playstic Limit , Plasticity İndex	LL < 25 - PI < 6	ASTM D 4318 AASHTO T 89&90
Clay Lumps and Friable Particle(%)	< 1	ASTM C 142
Aggregate Impact Value Test (%)	< 25	BS 812:112
Flaky &Elongated Particle	< 30	ASTM D 3398 - BS 812
Sand Equivalent Value (%)	> 45	ASTM D 2419 - AASHTO T 176
Passing 0,075 sieve divided by passing 0,425 sieve , ratio	The fraction passing the 0,075 mm mm sieve shall not be greater 2/3 of the fractions passing the 0,425 mm	AASHTO T 193

Table 4 – This table presents the results of laboratory tests conducted on base course materials from five different sources

Property	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Specification Limits	Testing Method
Los Angeles Abrasion Value(%)	18,5	17,2	37,0	49,3	47,0	< 50	ASTMC131 AASHTO T 96
Liquid Limit, Playstic Limit , Plasticity İndex	Non Plastıc	Non Plastıc	Non Plastıc	Non Plastıc	Non Plastıc	LL < 25 - PI < 6	ASTM D4318 AASHTOT89&90
Sıeve Analysıs - Gradation	Gradation B	Gradation C	NOT SUITABLE	Gradation B	Gradation D	-	ASTMD1241
Flaky &Elongated Particle	14,5	15,6	-	-	-	< 30	ASTMD3398 - BS 812
Sand Equivalent Value (%)	70,5	69,2	65,3	55,4	-	> 45	ASTMD2419 - AASHTO T 176
Aggregate Impact Value Test (%)	9,8	8,36	15,25	16,75	15,96	< 25	BS 812:112
Clay Lumps and Friable Particle(%)	0,25	0,31	0,52	-	-	< 1	ASTM C 142
Maximum Dry Density gm/cm³	2,196 / 5,5	2,160/ 10,6	2,145/ 4,9	2,222/ 5,3	2,213/ 5,8	-	AASHTOT180 Method D
CBR %	182,80	122,40	75,6	167,4	162,8	> 80	AASHTOT180 Method D
Passing 0,075 sieve divided by passing 0,425 sieve , ratio	0.425 = 23,0 0.075 = 8,0	0.425 = 22,3 0.075 = 9,2	0.425 = 37,4 0.075 = 7,3	0.425 = 19,5 0.075 = 6,0	0.425 = 31,0 0.075 = 10,0	The fraction passing the 0,075 mm mm sieve shall not be greater 2/3 of the fractions passing the 0,425 mm	AASHTO T 193

Table 5: The Base Course Materials Sieve Analysis Results And Gradation Control

Sieve Size(mm)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
50	100	100	100	100	100
25	90,3	100	98,3	89	100
9,5	56,7	62,6	62,5	57,5	74,7
4,75	40,6	46,3	50,6	41,5	59,6
2,00	32,1	33,9	43,1	30,6	49,0
0,425	23,0	22,3	37,4	19,5	31,0

The Figures 1-5 illustrate the gradations of the base course obtained from various sources:

Figurer 1, Sample 1 from the Mahroga Crusher Plant Base Course indicates that the gradation complies with the specifications of Class B as outlined in ASTM D 1241.

Figure 2 from Sample 2, sourced from the AlBartama Crusher Plant Base Course, indicates that the gradation complies with the specifications of Class C as outlined in ASTM D 1241

Figure 3 illustrates that the gradation of Sample 3 from the Brack – Ash Shwayrif Road at KM: 20+000 for the base course does not meet the specifications outlined in ASTM D 1241. Figure 4, Sample 4 from the Murzug Granular Base Course indicates that the gradation complies with the specifications outlined in Class B as per ASTM D 1241.

Figure 5 from Sample 5, sourced from Ghadwa Granular Base Course, indicates that the gradation complies with specification class D as outlined in ASTM D 1241.

Gradation Control

Gradation control is a crucial aspect of base course material selection. The gradation of the aggregates determines how well the material will compact and how it will perform under traffic loads. A well-graded material will have a balanced distribution of particle sizes, allowing for optimal compaction and stability. Poorly graded materials, on the other hand, may lead to issues such as poor drainage, inadequate load distribution, and reduced pavement life. In this study, the gradation of the materials was evaluated using sieve analysis, and the results were compared against the ASTM D1241 [11] specifications. Samples 1, 2, 4, and 5 met the gradation requirements, while Sample 3 did not, indicating that it may not perform well in a base course application.

In summary, the tables and gradations presented in this study provide a comprehensive evaluation of the physical and mechanical properties of base course materials. These results are essential for ensuring that the materials used in highway construction meet the necessary standards for stability, durability, and performance. Proper material selection, based on these tests, is critical for the long-term success of road infrastructure.

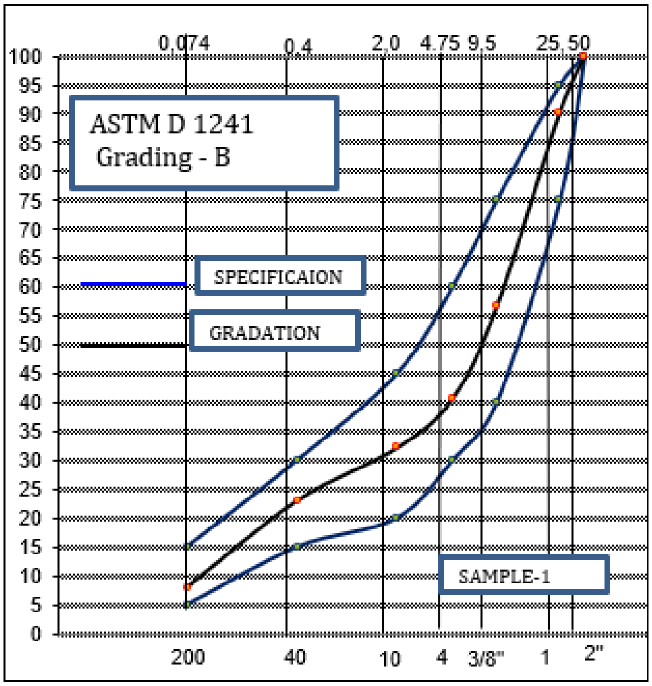

Fig. 1: Grading- B

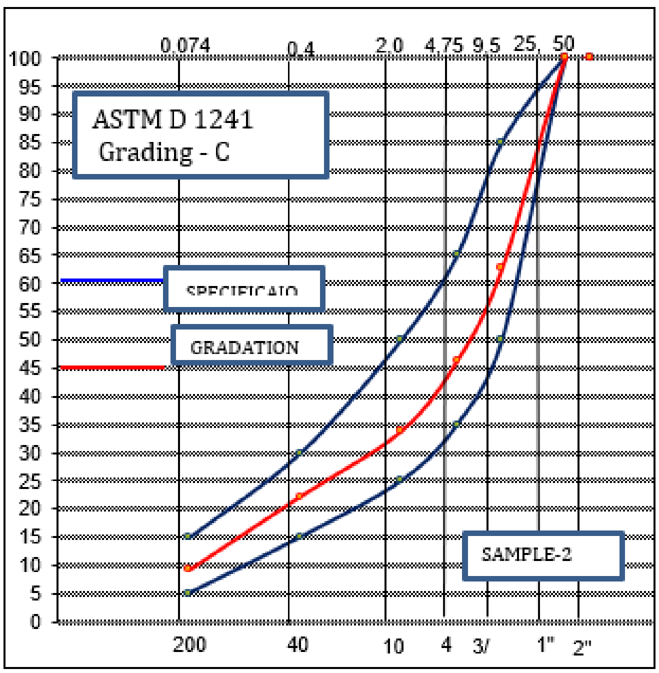

Fig. 2: Grading- C

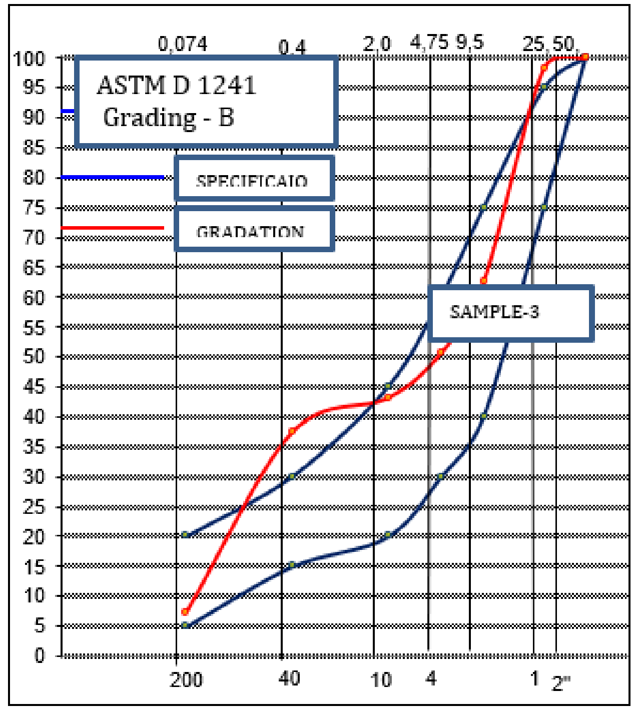

Fig. 3: Grading-B

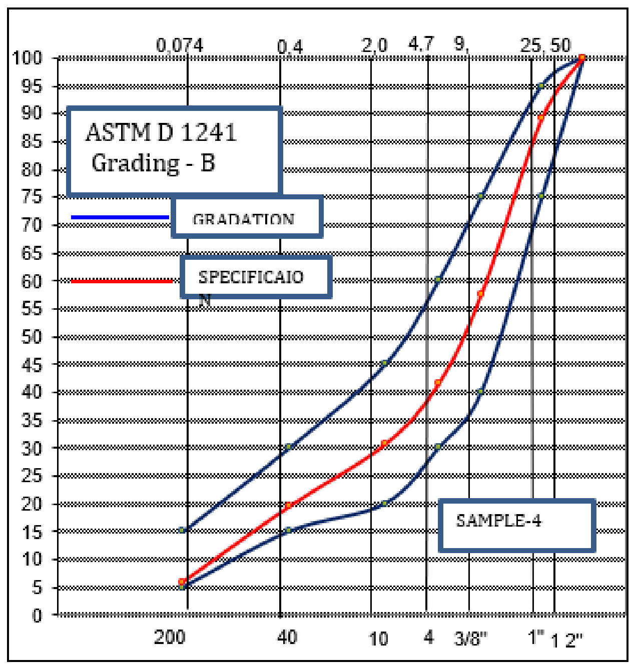

Fig. 4: Grading-B

Discussion and evaluation

The base course is a critical element of road construction, serving as the foundation for the pavement and ensuring its stability, durability, and performance. Proper material selection, gradation, and compaction are essential to the effectiveness of the base course. A well-constructed base course not only provides a strong foundation but also facilitates drainage, playing a vital role in the longevity and safety of the road. A robust base course must never be placed on a soft or yielding subgrade, as such conditions compromise the structural integrity of the pavement. Soft subgrades often result from inadequate compaction or excessive moisture content. Spongy subgrades may stem from wet materials beneath the surface or the presence of highly micaceous soils, which exhibit poor stability regardless of moisture content. Subgrade soils in the A-4 and A-5 groups, characterized by low plasticity, are particularly weak and should be removed to a depth of at least one foot and replaced with better-quality material. In cases where replacement is not feasible, stabilization techniques should be employed to enhance subgrade performance.

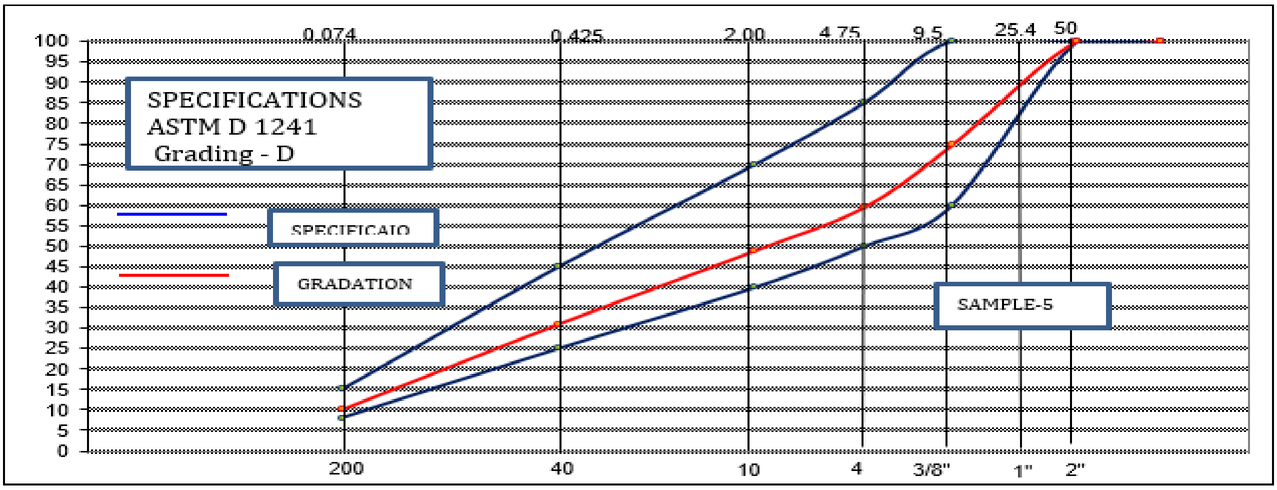

Fig. 5: Grading-D

To evaluate the suitability of base course materials, a comprehensive laboratory testing program was conducted on aggregate samples collected from various pavement sites. These tests included:

- **Standard Compaction:** To determine the maximum dry density and optimum moisture content of the materials, ensuring adequate compaction.
- **Particle Size Analysis:** To assess the gradation of the aggregates and verify compliance with ASTM D124 specifications.
- **Atterberg Limits:** To evaluate the plasticity characteristics of the materials, as non-plastic aggregates are preferred for base courses.
- **Wet California Bearing Ratio (CBR) Testing:** To measure the strength and load-bearing capacity of the materials under simulated field conditions.
- **Los Angeles Abrasion Test:** To determine the resistance of the aggregates to wear and degradation under traffic loads.
- **Impact Value Test:** To assess the toughness and resistance of the aggregates to sudden impacts.
- **Clay Lumps and Friable Particles Test:** To identify and quantify weak particles in the aggregates.
- **Flakiness Index Test:** To evaluate the shape characteristics of the aggregates, as flaky particles can negatively affect compaction and stability.

The primary objective of these tests is to ensure that the base course is capable of demonstrating satisfactory performance over the 20-year service life of a flexible pavement. This involves minimizing deformation, cracking, and other forms of distress under anticipated traffic loads.

The results of this study emphasize the critical importance of adhering to established material specifications and testing protocols. Aggregates must exhibit adequate gradation, strength, and durability to withstand the mechanical and environmental stresses encountered during the pavement's service life. Materials that fail to meet these requirements, such as those with poor CBR values or excessive plasticity, should be avoided or improved through stabilization methods.

CONCLUSION

Afterwards, both physical and chemical test results must meet the desired specification values. Particular attention should be paid to the mixture gradation. The prepared base material • Soil classification according to ASTM standards should be a good base Gw, Gp, Gw-Gm, Gw-Gc. It should meet the specification limits specified as A-1-a, A-1-b according to AASHTO standards.

As a result of the CBR tests performed on the prepared mixtures, there should be no swelling rate and the CBR should be at least 80%.

As a result of the tests, the results of the base course mixtures made with crushed stone are better than the granular base course. Los Angeles results are more efficient.

Samples 1, 2, 4 and 5 are suitable in terms of gradation limits. Sample 3 does not comply with the Astm D 1241 gradation rating.

As a result of the Cbr test performed on Sample 3, it was seen that it did not meet the specification value.

As a result, in order to increase the quality and durability of the roads, manufacturing should be carried out with a crushed base course as a priority, considering the heavy traffic conditions.

When all tests are evaluated, the base course material prepared in Mahroga Crushe Plant meets all the desired physical and chemical results. The mixture gradation is in the specification values and in A-1-a class.

Author Contributions: "It's a single-author article."

Funding: "This research received no external funding."

Data Availability Statement: "The data are available at request."

Conflicts of Interest: "The author declares no conflict of interest."

REFERANCE

[1] R. Ghabchi, M. Zaman, P. Solanki, and H. Kazmee. "Performance Evaluation of Aggregate Bases with Varying Gradation and Moisture Content in Different Climatic Conditions." *Journal of Pavement Research Technology*, vol. 14, no. 1, pp. 45-59, 2021.

[2] H. Salem, and A. Ihssian. "The Impact of Roadway Cross-section Elements' Design and Conditions on Road Safety: A Case Study of Alshwarif-Brack Road." *Wadi Alshatti University Journal of Pure and Applied Sciences*, special issue, pp. 40-46, 2025. https://www.waujpas.com/index.php/journal/article/view/ 130

[3] H. Salem. "Effect of Polymer Modification Bitumen on Performance of Flexible Pavement in Hot Arid Area in Libya," *Wadi Alshatti University Journal of Pure and Applied*

Sciences, vol. 1, no. 1, pp. 57-63, 2024. https://www.waujpas.com/index.php/journal/article/view/19

[4] A. Hassan, and A. Albarkuoli. "Comparative Study of Physical and Mechanical Properties of Base Course Materials from 3 Different Gravel Pits within the Municipality of Brack Alshatti, Libya." *Wadi Alshatti University Journal of Pure and Applied Sciences*, special issue, 94-99, 2025. https://doi.org/10.63318/ waujpas.sp1FCRTA-2024_14

[5] H. Salem. "Enhanced Asphalt Mixture Design for Sustainable Pavements." *Wadi Alshatti University Journal of Pure and Applied Sciences*, vol. 2, no. 2, pp. 31-35, 2025. https://www.waujpas.com/index.php/journal/article/view/73

[6] M. Misbah, A. Al-Tarhoni, and I. Aboodina. "Some Asphalt Plants in Libya; Classification and Performance Evaluation." *University of Zawia Journal of Engineering Sciences and Technology*, vol. 2, no. 2, pp. 218–225, 2024. https://doi.org/10.26629/uzjest.2024.20

[7] H. Salem, M. Miskeen, and Y. Salem. "Enhanced Performance of Asphalt Mixtures by Adding Recycled Rubber from Damaged Car Tires." *Wadi Alshatti University Journal of Pure and Applied Sciences*, special issue, pp. 1-11, 2025. https://www. waujpas.com/index.php/journal/article/view/165

[8] H. Salem. "A Comprehensive Evaluation of Polymer Additives in Modified Bitumen for Enhanced Pavement Performance." Sebha University Conference Proceedings, vol. 3, no. 2, pp. 259-263, 2024.

[9] R. Harshavardhan. "Evaluation of Fracture Toughness of Red Mud Reinforced Aluminum Matrix Composite" 2018.

[10] S. Pranshul, and R. Kamble. "Experimental Study on Design of Flexible Pavement using Atterberg Metho**d**'' *International Journal of Mechanical And Production Engineering*, vol. 5, no. 11, 2017

[11] ASTM D1241-20: Standard Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses (2020) Updates the specification limits and requirements for base course materials.

[12] A. Dawson et al. "Mechanistic-Empirical Analysis of Flexible Pavements Under Heavy Traffic and Environmental Loading" *Transportation Geotechnics*, 2020

[13] A. Dawson, M. Mundy, and M. Huhtala. "European Research Advances into Pavement Bases." *Journal of Transportation Infrastructure Research*, vol. 16, no.5, pp. 245-263, 2020.

[14] P. Jayawickrama, D. Allen, and C. Hettiarachchi. "Advances in Understanding the Mechanical Behavior of Base and Subbase Materials under Traffic Loading." *International Journal of Road Materials and Pavement Design*, vol. 21, no. 3, pp. 345-361, 2020.

[15] P. Jayawickrama."Improved Characterization of Unbound Base/Subbase Layers for Mechanistic Pavement Design" *Transportation Research Record (TRR)*, 2020

[16] H. Ozturk, and A. Yuksel. "Impact of Gradation on Durability and Stability of Base Course Materials." *Transportation Research Record*, vol. 2675, no. 4, pp. 34-45, 2022.

[17] H. Ozturk, and A. Yuksel. "Optimization of Gradation for Unbound Granular Base Courses to Enhance Mechanical Performance." *Construction and Building Materials*, 2022.

[18] Y. Huang, and L. Xu. "Sustainability in Pavement Materials: A Review on the Use of Recycled Aggregate in Base Layers." *Resources, Conservation & Recycling*, 191, 106888, 2023.

[19] AASHTO Guide for Design of Pavement Structures. Provides the latest guidelines for pavement design, including the selection of base course materials, 2021.