GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Evaluation of the stiffness modulus of a 0/14 bituminous concrete as a function of temperature

Hermann Durand OHOUO *, Séraphin Agré DJOMO and Ulrich Raoul Blé KOUASSI

Laboratory of Environmental Sciences and Technologies, Jean Lorougnon Guédé University of Daloa, BP 150 Daloa. CÔTE D'IVOIRE

GSC Advanced Research and Reviews, 2025, 25(03), 366-373

Publication history: Received on 12 November 2025; revised on 29 December 2025; accepted on 31 December 2025

Article DOI: https://doi.org/10.30574/gscarr.2025.25.3.0397

Abstract

In Côte d'Ivoire, the development of the road network represents a major challenge for the national economy, with more than 80% of interurban transport carried out by road. However, bituminous pavements are subjected to mechanical and climatic stresses that accelerate their degradation. Among the factors influencing their durability, temperature plays a decisive role in the mechanical properties of asphalt mixtures, particularly the stiffness modulus. This study addresses this issue by evaluating the evolution of the stiffness modulus of a 0/14 bituminous concrete as a function of temperature.

The study was conducted at the Laboratory of Building and Public Works (LBTP) using aggregates from massive rocks and a 60/70 grade bitumen. Experimental methods included aggregate characterization tests (particle size distribution, sand equivalent, Los Angeles, Micro-Deval), bitumen tests (penetration, softening point), as well as mechanical tests (Marshall, Duriez, rutting, stiffness modulus according to NF EN 12697-26).

The results show that the stiffness modulus decreases significantly with increasing temperature: above 5000 MPa at 10°C, it drops to less than 1000 MPa at 40°C. This variation reflects a loss of rigidity and mechanical performance, making the asphalt more vulnerable to deformation. These findings highlight the need to adapt asphalt formulations to local climatic conditions to ensure pavement durability.

Keywords: Bituminous Concrete; Stiffness Modulus; Temperature; 0/14 Asphalt; Mechanical Performance

1. Introduction

The development of road infrastructure constitutes a fundamental lever for the economic and social growth of Côte d'Ivoire. Since the early post-independence years, Ivorian authorities have invested in expanding the road network in order to facilitate trade, passenger transport, and regional integration. Today, more than 80% of interurban and interstate traffic relies on roads, which gives these infrastructures a strategic role in the national development dynamic [1].

However, this road network faces major challenges related to durability. Bituminous pavements, in particular, are subjected to intense mechanical stresses from heavy traffic as well as climatic aggressions that progressively reduce their performance. Premature aging signs such as cracks, rutting, and deformations are frequent, compromising user comfort and safety [2]. These degradations are often exacerbated by a mismatch between road design techniques and local geotechnical characteristics [3].

* Corresponding author: Hermann Durand OHOUO.

Among the parameters influencing the performance of asphalt mixtures, temperature plays a decisive role. Indeed, the mechanical properties of hot mix asphalt, particularly its stiffness modulus, vary greatly depending on thermal conditions. At low temperature, the material becomes rigid and brittle, while at high temperature, it loses cohesion and becomes more susceptible to plastic deformations. This thermal sensitivity can compromise pavement durability if it is not properly considered in mix design and structural dimensioning studies.

In this context, the present work is part of an effort to evaluate the thermal performance of a 0/14 hot mix asphalt used as a wearing course in Ivorian pavements. The general objective of this study is to analyze the evolution of the stiffness modulus of this material as a function of temperature, in order to better understand its mechanical behavior and identify critical thermal conditions likely to affect its durability.

To this end, a series of laboratory tests was carried out at LBTP, focusing on asphalt mix formulation, mechanical characterization, and stiffness modulus analysis at different temperatures. The results obtained will make it possible to formulate technical recommendations for adapting asphalt mixtures to local climatic realities, thereby contributing to the improvement of the quality and longevity of road infrastructure in Côte d'Ivoire.

2. Materials and Methods

The study was carried out at the Laboratory of Building and Public Works (LBTP) of Côte d'Ivoire, as part of an experimental evaluation of the stiffness modulus of a 0/14 hot mix asphalt subjected to different temperatures.

2.1. Materials used

Derived from massive rocks, the aggregate fractions used are graded according to the particle size classes 0/4, 4/10, and 10/14. The bitumen is of grade 60/70, selected for its medium penetration and thermal stability. It is incorporated at a proportion of 5 to 7% by mass in the mix design. The formulation of the 0/14 bituminous concrete (BB 0/14) is a gap-graded asphalt mixture, intended to simulate a wearing course subjected to heavy traffic.

3. Characterization Methods

3.1. Tests on aggregates

3.1.1. Granulometry

Particle size analysis is a fundamental method used to determine the dimensional distribution of solid particles within a granular material. It is essential for ensuring the compaction, stability, and mechanical performance of asphalt mixtures. According to the NF EN 933-1 standard, the test consists of passing a known mass of dry aggregates through a series of standardized sieves with decreasing mesh sizes. Each retained fraction is weighed, which makes it possible to calculate the cumulative passing percentage and to plot the particle size distribution curve.

3.1.2. Sand equivalent

The sand equivalent test (NF EN 933-8) is used to assess the cleanliness of fine aggregates, particularly their content of clay fines that may impair adhesion between the bituminous binder and the aggregates. It is an essential indicator for evaluating the quality of sands used in asphalt mixtures.

3.1.3. Los Angeles and Micro-Deval

The Los Angeles test (NF EN 1097-2) is used to evaluate the resistance of aggregates to fragmentation under the effect of mechanical impacts. It is particularly important for materials intended for pavement wearing courses, where dynamic stresses from traffic can lead to premature degradation of the aggregates.

The Micro-Deval test (NF EN 1097-1), on the other hand, is used to assess the resistance of aggregates to wear caused by friction in the presence of water. It is especially relevant for materials used in pavement wearing courses, where hydromechanical stresses are frequent. This test complements the Los Angeles test by focusing on wear due to abrasion rather than fragmentation by impact.

3.2. Tests on Bitumen

3.2.1. Bitumen penetration

The penetration test (NF EN 1426) is used to determine the consistency of bitumen at ambient temperature. It is a fundamental indicator for assessing the hardness or softness of the binder used in asphalt mixtures. This property directly influences the workability of the hot mix, its thermal sensitivity, and its ability to resist deformation under traffic. The result obtained is called the penetration index. The higher the value, the softer the bitumen; conversely, a lower penetration indicates a harder bitumen.

3.2.2. Softening point

The Ring-and-Ball softening point test (NF EN 1427) is used to determine the temperature at which bitumen transitions from a solid state to a viscous state. It is an essential indicator of the thermal sensitivity of the binder, directly influencing the behavior of bituminous concrete under the effect of heat.

3.3. Mechanical Testing of Asphalt Mixtures

3.3.1. Marshall stability

The Marshall test is a classical method used to evaluate the mechanical strength and stability of a compacted asphalt mixture. It determines the material's ability to withstand vertical loads induced by road traffic, while also measuring its deformability (flow). This test, carried out according to the NF EN 12697-34 standard, is essential for optimizing the formulation of asphalt mixtures and ensuring their performance in service. The two main parameters obtained are Marshall stability (kN), which represents the mixture's capacity to resist compressive force, and flow (mm), the plastic deformation under load, serving as an indicator of the mixture's flexibility.

3.3.2. Bitumen Extraction Test

This test evaluates the content of soluble binder in asphalt mixtures. Conducted according to the NF EN 12697-1 standard, it is an essential tool for quality control and conformity verification of road asphalts. The test aims to accurately determine the proportion of binder present in a mixture. This information is indispensable for verifying compliance with mix design specifications, ensuring production quality at the plant, controlling materials during recycling operations, and providing reliable data for studies on pavement durability and mechanical performance.

3.3.3. Duriez water sensitivity

The Duriez test (NF P 98-251-1) is used to evaluate the water sensitivity and internal cohesion of a compacted asphalt mixture. It measures the material's ability to retain its mechanical properties in a humid environment, which is essential for pavements exposed to weathering and water infiltration. A conservation index greater than 75% is generally considered satisfactory for asphalt mixtures.

3.3.4. Rutting resistance

The rutting test (NF EN 12697-22) is used to measure the resistance of an asphalt mixture to the formation of permanent longitudinal deformations known as ruts. These deformations are caused by the repeated passage of rolling loads, particularly heavy vehicles. The test is essential for evaluating the performance of the pavement under conditions of intense traffic and high temperature. The depth of the rut formed at the center of the slab is measured at regular intervals, up to a defined number of cycles (e.g., 10,000 to 30,000 cycles). The main indicator is rut depth (mm), which reflects the sensitivity of the mixture to plastic deformation.

3.3.5. Stiffness modulus

The stiffness modulus test (NF EN 12697-26) is used to quantify the ability of an asphalt mixture to resist deformation under dynamic loading. It is a fundamental parameter in pavement design, as it reflects the rigidity of the material as a function of temperature and loading frequency. The modulus is highly dependent on temperature because, as the latter increases, the material becomes more flexible and less rigid.

4. Results

4.1. Material Characteristics

4.1.1. Particle Size Analysis

As part of this research, particle size analysis was carried out on the 0/4, 4/10, and 10/14 fractions used in the formulation of the 0/14 bituminous concrete. The resulting curves (Figure 1) confirmed the proper distribution of grain sizes and the compatibility of the aggregates with the technical specifications of High Modulus Asphalt Concrete (BBME). The cumulative particle size curve, obtained by weighting the fractions SAND 0/4, GRAVEL 4/10, and GRAVEL 10/14, reveals a broad and continuous distribution of particles.

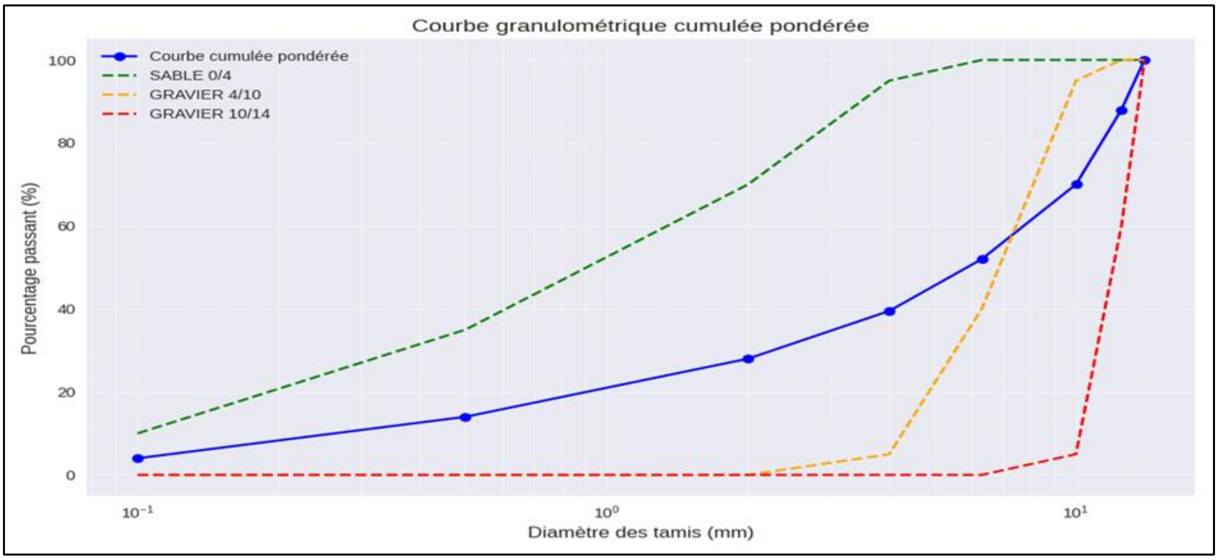

Figure 1 Particle Size Distribution Curve

This profile promotes optimal compaction and a dense granular skeleton, thereby improving the stiffness modulus of the mixture, reducing porosity, and ensuring good mechanical stability. The mixture meets the gradation criteria recommended for road foundation layers and pavement concretes, in accordance with NF P 18-560 and ASTM C33 standards. These results confirm the value of a carefully designed particle size distribution in enhancing the performance of road materials in tropical environments.

4.1.2. Sand Equivalent

The sand equivalent test carried out on the 0/4 sand fraction yielded a value of 63%, which is higher than the minimum threshold of 60% required by LBTP specifications. This result confirms the cleanliness of the sand and its low content of clay particles. It is therefore suitable for use in pavement layer formulations.

4.1.3. Resistance to Fragmentation (Los Angeles) and to Wear (MDE)

The wear resistance tests carried out according to NF EN 1097-2 yielded values of 24% for the 4/10 gravel and 20% for the 10/14 gravel, both below the 35% threshold set by LBTP specifications. These results indicate good to very good mechanical resistance of the aggregates, making them suitable for use in wearing courses, foundations, and road concretes. As for the Micro-Deval test results, they revealed mass losses of 9% for the 4/10 gravel and 6% for the 10/14 gravel, both below the 10% threshold set by LBTP specifications. These values demonstrate good to excellent resistance to wear by wet abrasion, confirming the suitability of the aggregates for use in water-saturated or heavily stressed environments. Combined with the Los Angeles test results, these findings lead to the conclusion of the overall mechanical robustness of the studied materials.

4.2. Results of Bitumen Characterization

4.2.1. Needle Penetration Test

The needle penetration test carried out at 25°C yielded a value of 41.7 (1/10 mm), in compliance with the specifications of 35 to 50. This result indicates an intermediate consistency of the binder, ensuring a good balance between flexibility and rigidity. It is particularly suitable for tropical climatic conditions, where thermal stability and resistance to flow are essential. This level of penetration guarantees good workability of the binder, effective adhesion to aggregates, and satisfactory durability of road structures. [4] emphasize that the quality of aggregates and binder is decisive. The tests conducted at LBTP show that the materials used comply with standards, but their behavior remains sensitive to thermal stresses, which is consistent with the conclusions of [3] regarding the inadequacy of conventional techniques to local realities.

4.2.2. Softening Point Test

The softening point test yielded a value of 53.6°C, in compliance with the specifications of 50 to 58°C. This result indicates good thermal stability of the binder, making it suitable for use in tropical environments. It ensures satisfactory in-service performance by limiting the risks of flow or bleeding under high temperatures. This thermal behavior, combined with balanced penetration, confirms the relevance of the binder for wearing courses and bituminous formulations intended for road infrastructures in hot climates.

4.3. Mechanical Performance

4.3.1. Marshall Stability

The results of the mechanical tests carried out on three samples of asphalt mixture reveal overall compliance with LBTP specifications (see Table 1).

Table 1 Results of the Marshall Test

Désignation	**Results**			**LBTP Specifications**
Sample	1	2	3	
Stability (Kg)	1152	1230	1215	≥1000
Flow (1/10mm)	34.30	32.93	34	≤40
DAH	2.42	2.40	2.39	-
Compaction (%)	94	95	96	94-97

The Marshall stability values, all above 1000 Kg, indicate excellent resistance to deformation under load. The flow values, below 40 (1/10 mm), confirm the rigidity of the mixture and its ability to resist flow in tropical climates. The harmonized bulk densities are homogeneous, reflecting good manufacturing control. Finally, compaction rates between 94% and 96% ensure low porosity and optimal durability. These results validate the formulation for use in wearing courses or road structures subjected to heavy traffic. [5] emphasizes the importance of a well-calibrated formulation to guarantee mixture cohesion. The Marshall stability and compaction results confirm that the BB 0/14 formulation used is mechanically efficient at moderate temperatures, but loses effectiveness under intense heat.

4.3.2. Results of the Binder Extraction Test

The results of the binder extraction tests are presented in Table 2.

Table 2 Results of Binder Extraction

Designation	**Results**	**LBTP Specifications**
External binder (%)	5.66	≈ 6
Fines/bitumen ratio	0.71	-
Richness modulus	3.60	3.50-3.80

Water content W (%)	0.054	-
True density	2.48	-

The binder extraction carried out on the studied sample revealed an external binder content of 5.66%, close to the reference value (≈6%). The richness modulus obtained (3.60) falls within the normative range (3.50–3.80), indicating a good balance between rigidity and workability. The fines/bitumen ratio (0.71) and the low water content (0.054%) confirm the cohesion and compactness of the mixture. The true density (2.48) corresponds to the usual values of natural aggregates, ensuring good mineralogical stability. Overall, these results demonstrate the conformity of the material with LBTP specifications and its ability to deliver durable performance in service.

4.3.3. Water Resistance (Duriez Test)

The water resistance results showed a conservation index greater than 80% (see Table 3), indicating good resistance to moisture and stable internal cohesion.

Table 3 Water Resistance Results

Designation	**Résults**	**LBTP Specifications**
Compressive strength at 18°C (bar)	83	≥70
Strength after 7 days immersion (bar)	63	–
Immersion/Compression ratio	0.76	≥0.70
Hydrostatic density (t/m^3)	2.27	–
True density (t/m^3)	2.48	–
Duriez compaction (%)	92	90–94

The results showed a conservation index greater than 80%, reflecting good moisture resistance and stable internal cohesion. This performance is favorable for pavements in tropical climates, where cycles of humidity and heat can affect the durability of surfacings. The test confirms that the studied mixture retains its mechanical properties even after prolonged immersion, reinforcing its suitability for wearing courses subjected to variable moisture conditions.

4.3.4. Rutting

The rutting results of the 0/14 asphalt concrete show a rut depth of 3.18 mm at 10,000 cycles, with a relative percentage of 5.27%. All values are below 9 mm after 10,000 cycles (see Figure 2), which indicates good resistance to deformation.

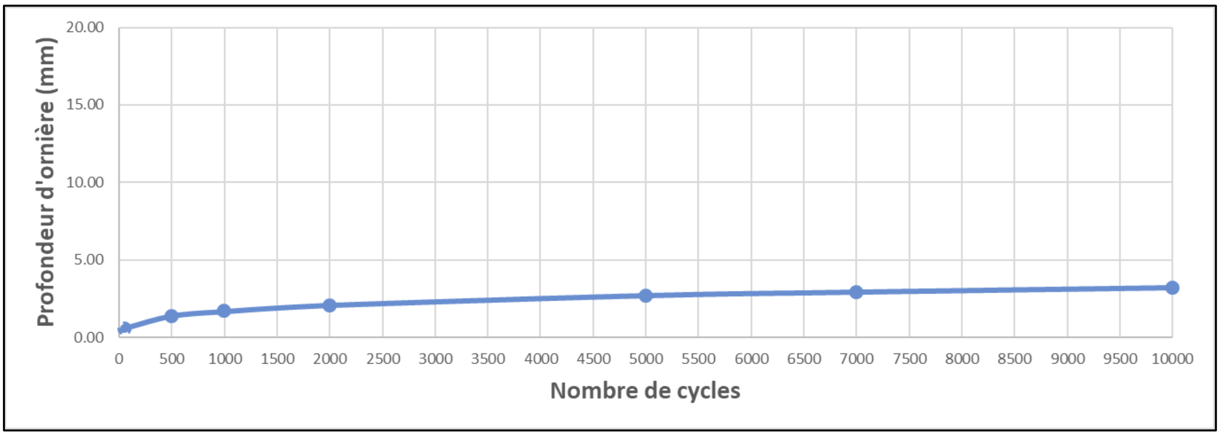

Figure 2 Rut Depth Curve as a Function of the Number of Cycles

The rutting slope (WTSw) is 0.10 mm/1000 cycles, indicating a slow and controlled progression of deformation. These results confirm the good resistance of the material to creep and its stability under repeated traffic. The low variability between the two specimens demonstrates the homogeneity of the mixture and the reliability of the manufacturing conditions. Overall, the material meets performance requirements in terms of rutting resistance and can be considered durable for use in wearing courses.

4.3.5. Stiffness Modulus

Les essais de module complexe réalisés à différentes températures et fréquences (voir tableau 4) mettent en évidence le comportement thermo-viscoélastique du matériau. À 15 °C et 10 Hz, le module atteint plus de 10 000 MPa, traduisant une rigidité élevée.

Table 4 Complex Modulus Results

Temperature (°C)		**15**	**25**	**30**	**40**
Fréquency (Hz)		4Hz			
Modulus	E1	9200	5284	3666	2318
	E2	8399	4669	3517	2059
Fréquency (Hz)		7Hz			
Modulus	E1	10389	5961	4442	2318
	E2	9484	5443	4054	2117
Fréquency (Hz)		10Hz			
Modulus	E1	10514	6365	4990	2318
	E2	9599	5914	4459	2145

Conversely, at 40°C and 4 Hz, it drops to around 2100–2300 MPa, revealing strong thermal sensitivity. Increasing the frequency raises rigidity by 15 to 25%, confirming the influence of rapid traffic on mechanical response. The two specimens show similar results, attesting to the homogeneity of the mixture. Overall, these findings confirm that the material meets performance requirements in terms of resistance to deformation and durability, while also illustrating the limitations associated with extreme temperature and loading conditions. The results obtained confirm the observations of [6], who emphasize that the stiffness modulus is highly dependent on temperature. At low temperature (10°C), asphalt concrete exhibits high rigidity, corresponding to a brittle behavior but resistant to deformation. Conversely, at high temperature (40°C), rigidity drops drastically, making the material more ductile but vulnerable to rutting and plastic deformation. [7] demonstrated that very thin asphalt layers (BBTM) and high modulus asphalt (BBME) offer better resistance to thermal variations. In this context, the use of BBME could be considered for areas with heavy traffic and high temperatures, as suggested by [2] in his work on Ivorian pavements.

5. Conclusion

The study conducted on 0/14 asphalt concrete highlights the decisive impact of temperature on its stiffness modulus and, consequently, on its mechanical performance in service. The experimental results show high rigidity at low temperature, reflecting a brittle behavior but resistant to deformation, and a significant drop in rigidity at high temperature, making the material more ductile but vulnerable to rutting and plastic deformation. This thermal sensitivity confirms that the durability of pavements in tropical climates depends closely on the choice of materials and formulations. Thus, it appears necessary to adapt asphalt mixtures to local climatic conditions, notably through the use of modified binders or high-modulus asphalt concretes (BBME), in order to ensure better mechanical performance and increased longevity of road infrastructures. Integrating these recommendations into formulation and design practices will contribute to improving the quality of Ivorian pavements and sustainably supporting the development of the national road network. In continuation of this work, it would be relevant to deepen the study of asphalt concrete durability in tropical climates by incorporating parameters such as fatigue, binder aging, and the combined effect of moisture and thermal cycles. Exploring modified binders (polymers, nanostructured additives, recycled), alternative aggregates, or high-modulus formulations could provide solutions adapted to local conditions and enhance the longevity of Ivorian pavements.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] LBTP. (1979). *Guide to pavement design*. Abidjan.

[2] Klokouié, M. M. F. (2020). *Study of pavement durability in tropical climate*. Abidjan: LBTP.

[3] Memel, K. (2019). *Diagnosis of pavement degradations in Côte d'Ivoire*. Master's thesis. Daloa: Jean Lorougnon Guédé University.

[4] Bendimerad, F., Zadjaoui, A. (2015). *Study of mechanical properties of asphalt mixes*. Revue des Travaux Publics.

[5] Thiaw, M. (2006). *Formulation of asphalt mixes*. Master's thesis. Dakar: University of Dakar.

[6] Corté, J. F., Di Benedetto, H. (2005). *Mechanical behavior of bituminous materials*. Paris: LCPC.

[7] Halil, A., Khoudja, B. (2017). *Influence of temperature on asphalt performance*. Revue Génie Civil.