



PERFORMANCE-BASED LABORATORY STUDY ON ASPHALT MIXTURES UNDER TEMPERATURE AND TRAFFIC LOADING

Roxana Dermengiu^{1,2}, Carmen Răcănel¹, Mihai Dicu¹

¹Technical University of Civil Engineering of Bucharest, Romania

²S.C. CONSITRANS S.R.L., Romania

Abstract

This paper presents an experimental laboratory study focused on the performance based evaluation of asphalt mixtures, with emphasis on the influence of material properties and testing conditions on their mechanical behavior. The study investigates SMA 16 asphalt mixtures through a structured experimental program designed to analyze both material-related parameters and the effects of temperature and traffic-simulated loading. The first part of the study examines the quality and performance of the constituent materials. Bituminous binders are evaluated using classical and advanced rheological tests in order to assess stiffness, temperature sensitivity, and workability. In addition, the influence of the mineral aggregate skeleton is analyzed by comparing mixtures produced with aggregates from different sources, focusing on their effects on density, volumetric characteristics, and stiffness modulus. The role of polymer additives is also investigated, highlighting their contribution to improving mixture cohesion and resistance to permanent deformation. The second part of the study focuses on the influence of testing conditions representative of real service behavior. Dynamic laboratory tests performed on cylindrical and prismatic specimens are used to evaluate the variation of stiffness modulus with temperature and loading frequency, which is associated with traffic speed. Permanent deformation behavior is further investigated at different temperature levels, allowing the identification of critical performance trends under unfavorable thermal conditions. The experimental results provide a clear overview of the interaction between material composition and testing conditions, emphasizing their combined impact on key performance indicators such as stiffness modulus and resistance to permanent deformation. The findings confirm the usefulness of performance-based laboratory testing for the optimization of asphalt mixture design under realistic climatic and traffic-related conditions, supporting its application in engineering practice.

Keywords: asphalt mixtures, performance-based testing, stiffness modulus, temperature effects, loading frequency, permanent deformation

1 Introduction

The increasing traffic intensity, higher axle loads, and climatic variability impose stringent requirements on pavement performance. Surface asphalt mixtures must provide sufficient stiffness to withstand traffic loads while maintaining flexibility to limit cracking and permanent deformation. Performance-based evaluation has become essential for predicting long-term behavior under realistic service conditions. Within this framework, stiffness modulus and resistance to permanent deformation are key indicators, strongly influenced by temperature, loading frequency, and material composition.

SMA 16 is widely used for heavily trafficked surface layers due to its stone-on-stone aggregate structure, ensuring high rutting resistance and load-bearing capacity [1, 2]. Compared to finer SMA mixtures, it provides superior structural durability while maintaining adequate surface texture and acceptable acoustic performance [3, 4]. This study presents a structured experimental investigation of SMA 16 mixtures, analyzing the influence of binder type, aggregate source, additives, temperature, and loading frequency on mechanical performance.

2 Materials and experimental program

2.1 Asphalt mixture type

The experimental study was conducted on Stone Mastic Asphalt (SMA 16) mixtures, in accordance with SR EN 13108-5 and the national standard AND 605 [5]. This type of asphalt mixture is characterized by a strong mineral aggregate skeleton, a relatively high binder content, and the use of stabilizing fibers to prevent binder drainage.

2.2 Materials

Five binders (I-A, II-A, I-B, II-B, I-C), including conventional and polymer-modified types, were characterized through classical and SHRP tests (penetration, softening point, Fraass, DSR, BBR, Brookfield). Aggregates from two sources (X, Y) were evaluated in terms of mechanical and physical properties. Limestone filler and pelletized fibers were used in all mixtures, while selected variants incorporated a granular polymer additive.

2.3 Experimental program

The experimental program included SMA 16 mixtures produced with five binder types (I-A, II-A, I-B, II-B, I-C), two aggregate sources (X and Y), and stabilizing fibers, with selected variants incorporating polymer additives. All mixtures were evaluated through binder characterization and stiffness modulus determination using IT-CY and 4PB-PR configurations, followed by permanent deformation testing at elevated temperatures. The stiffness modulus master curve was constructed for mixture SMA16-II-A-X, selected as representative for detailed viscoelastic characterization.

3 Performance-based evaluation of materials

3.1 Binder performance

The rheological and physical characterization of the bituminous binders represents a key step in performance-based mixture design. The analysis carried out through classical tests and SHRP methodology highlights significant differences between conventional and polymer-modified binders. A comparative analysis of conventional binders (I-A, II-A, I-C) and polymer-modified binders (I-B, II-B) highlights significant differences in their rheological, thermal, and chemical behavior. This behavior is further supported by the performance indicators derived from the SHRP framework, presented in figures 1a and 1b, which show an extended plasticity interval and enhanced resistance to temperature extremes.

The results confirm that polymer modification leads to higher resistance to permanent deformation at elevated temperatures, while maintaining adequate flexibility at low temperatures, an essential requirement for surface layers exposed to heavy traffic and seasonal climatic variations. Figure 2 presents the variation of stiffness modulus as a function of binder type.

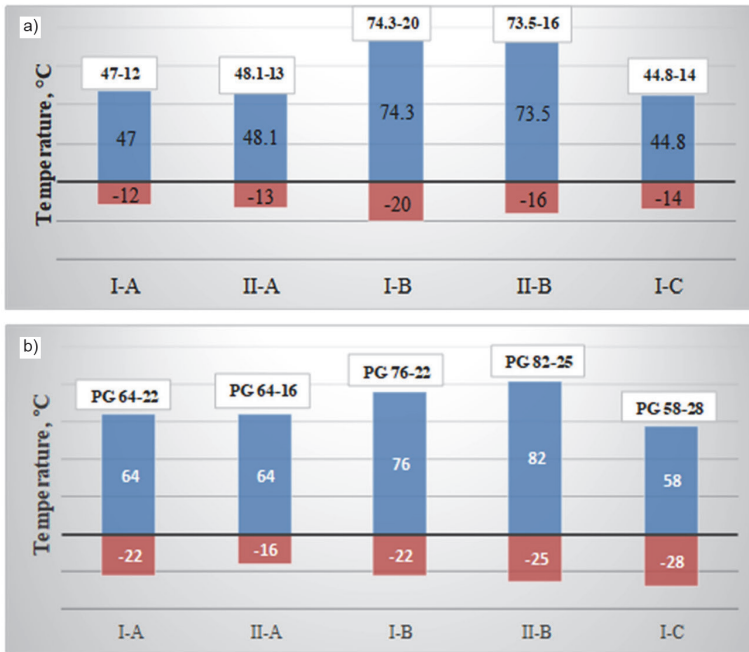


Figure 1 a) Plasticity interval, b) SHRP performance indicators for investigated binders

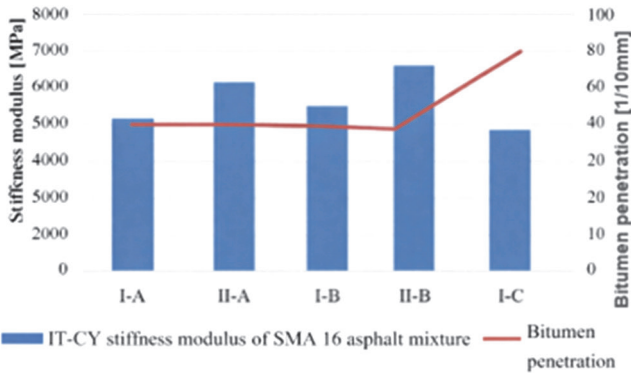


Figure 2 Influence of binder type on stiffness modulus of SMA 16 mixtures

The results show a clear dependence of stiffness modulus on bitumen consistency. The mixture containing the softer unmodified bitumen I-C, with a penetration of 84 (1/10 mm), presents a stiffness modulus about 36% lower compared to the mixture produced with bitumen II-B, which has a lower penetration value of 52 (1/10 mm).

3.2 Influence of aggregate skeleton

The influence of the mineral aggregate skeleton on mixture performance was evaluated by comparing SMA 16 mixtures produced with aggregates from two different sources (figure 3).

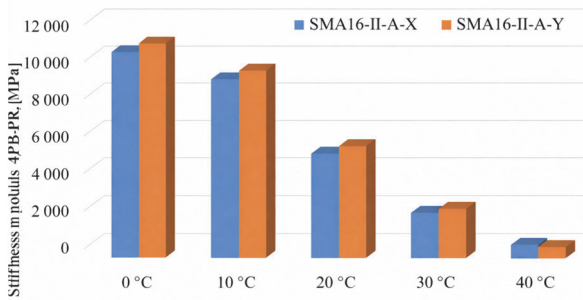


Figure 3 Influence of aggregate source on the stiffness of SMA 16 asphalt mixtures

Mixtures prepared with aggregates from source Y generally exhibited higher stiffness values, which can be attributed to improved particle interlock and superior mechanical properties of the aggregate skeleton. These findings underline the importance of aggregate selection in achieving balanced performance in SMA mixtures.

3.3 Influence of polymer additives

The experimental results confirm that polymer modification has a positive influence on the mechanical performance of SMA 16 asphalt mixtures. The use of polymer-modified bitumen enhances mixture cohesion and contributes to increased structural stiffness, despite a slightly lower density compared to the reference mixture.

4 Effect of temperature and loading conditions

The effect of environmental and loading conditions on mixture behavior was investigated through dynamic laboratory testing. Figures 3 and 4 present the variation of stiffness modulus with temperature and loading frequency, obtained from four-point bending tests.

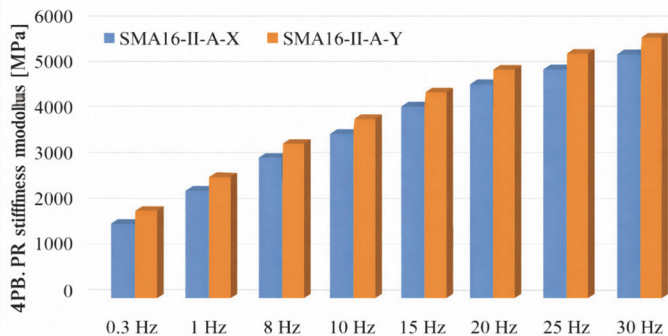


Figure 4 Variation of 4PB-PR stiffness modulus with loading frequency for SMA 16 asphalt mixtures

A pronounced decrease in stiffness modulus was observed with increasing temperature, confirming the susceptibility of asphalt mixtures to permanent deformation under high-temperature conditions. Conversely, increasing the loading frequency, associated with higher traffic speeds, resulted in increased stiffness values, reflecting the viscoelastic nature of the material. The comparison between cylindrical (IT-CY) and prismatic (4PB-PR) test configurations, illustrated in figure 5, reveals systematic differences in the measured stiffness modulus.

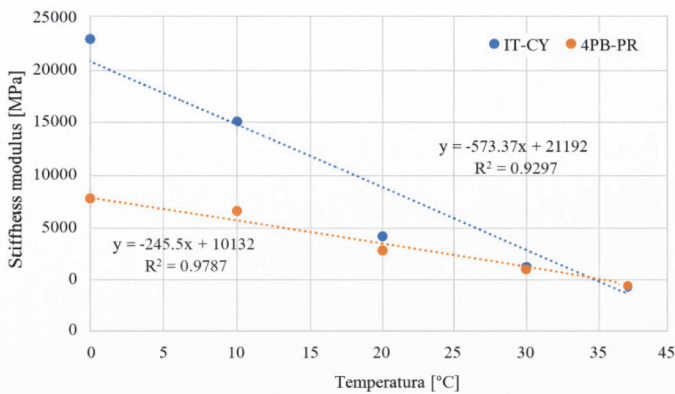


Figure 5 Variation of stiffness modulus with temperature determined by IT-CY and 4PB-PR tests

While IT-CY tests generally provide higher stiffness values, the 4PB-PR configuration offers a more realistic representation of in-service bending conditions, making it particularly suitable for performance-based evaluation. The master curve of the 4PB-PR stiffness modulus was developed for mixture SMA16-II-A-X (figure 6), selected as representative due to its conventional binder, defined aggregate source, and stable behavior across the tested temperature range. The curve confirms the strong time–temperature dependency of the material, with stiffness decreasing under prolonged loading and elevated temperatures.

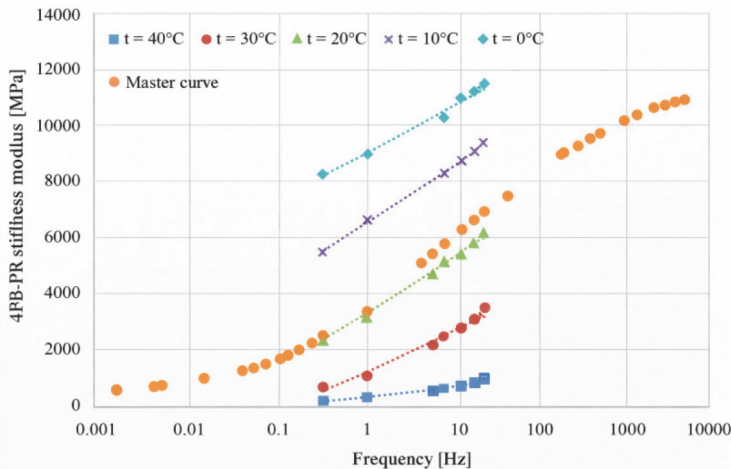


Figure 6 Master curve of 4PB-PR stiffness modulus constructed using time–temperature superposition

5 Permanent deformation behavior

The resistance to permanent deformation was further investigated at elevated temperatures representative of unfavorable service conditions. Figures 7a and 7b illustrate the evolution of deformation parameters with temperature, highlighting critical thresholds beyond which rapid stiffness degradation occurs. Permanent deformation increased nearly linearly with temperature ($R^2 = 0.9231$), highlighting the critical role of thermal conditions in rutting susceptibility.

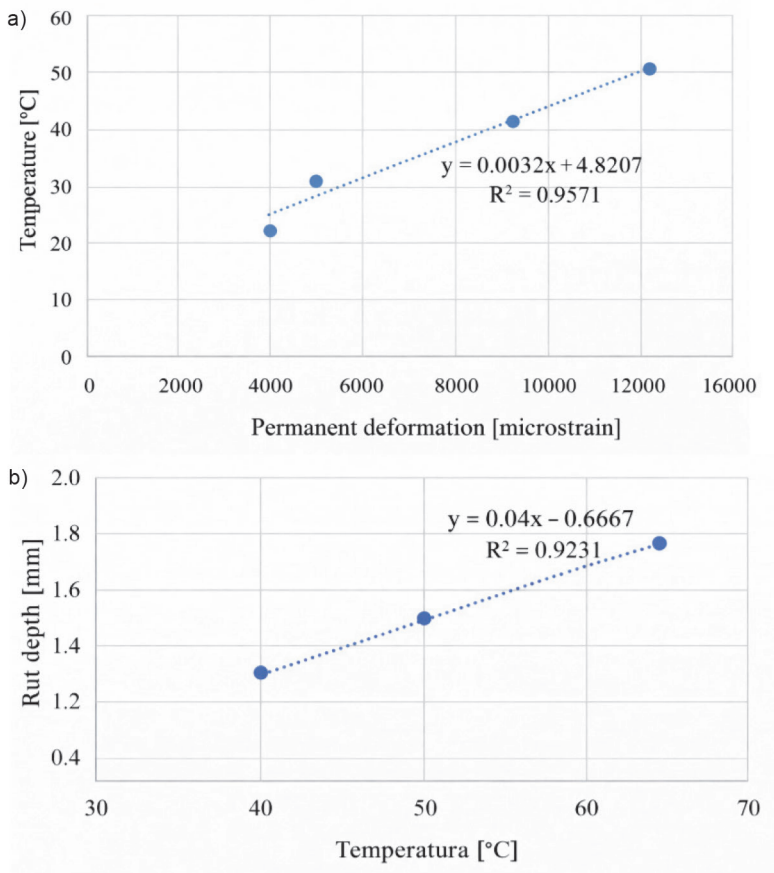


Figure 7 Relationship between permanent deformation and temperature

6 Conclusion

The study confirms that performance-based laboratory testing provides an effective framework for evaluating SMA 16 mixtures for heavily trafficked pavements. Binder type and aggregate source significantly influence stiffness and rutting resistance, while temperature and loading frequency govern viscoelastic response. Polymer-modified binders enhance high-temperature performance, and optimized aggregate skeletons improve structural rigidity. The developed master curve highlights the strong time–temperature dependency of mechanical behavior. These findings support the use of performance-based approaches for optimizing SMA 16 mixtures under realistic service conditions.

References

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