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DOI: 10.2478/rjti-2024-0002

ROMANIAN JOURNAL
OF TRANSPORT INFRASTRUCTURE

STUDY ON HIGH MODULUS ASPHALT MIXTURES

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Summary

In this article will be presented a comparison of a road structure dimensioning between a classical approach, which uses the information existing in the sizing norm in force, and a non-classical approach that uses performances of asphalt mixtures with high rigidity modulus, determined in the laboratory, by specific tests to determine the modules, which will be used in the dimensioning calculation.

Keywords: modulus of rigidity, modulus of elasticity, asphalt mixture, road structure design

1. INTRODUCTION

Asphalt mixtures are a mixture of aggregates and bituminous binder. The aggregates form the skeleton of the material. Although in a much smaller proportion than aggregates, bituminous binder gives the mixture a viscous behavior (linear viscoelastic with a small deformation) [1-3].

The main component material of the asphalt mixture in terms of complexity is bituminous binder. This is a product that presents at the same time a great complexity regarding its chemical composition and at the same time presents a response to mechanical stress [4,5].

Taking into account the characteristics of the bitumen used and the performances obtained by the asphalt mixtures manufactured with these bitumens, studies can be carried out on the dimensioning of the road structure according to the prospective traffic that will be recorded on the road [6,7].

At European level and not only, the modules used to size the road structure are the same module that were determined in the laboratory on asphalt mixture samples with different performances. In this way, there is a traceability between the performances obtained on asphalt mixtures and how the road structure will behave at different traffic demands.

High modulus asphalt mixtures or referred to in the literature as High Modulus Asphalt (HiMA) began to be used in France as early as the 1980s. These mixtures were considered a particularly good solution for avoiding the appearance of bumps on roads with heavy traffic [8,9].

Due to a higher bitumen content than for classical mixtures used as a base layer, the mechanical performance of these asphalt mixtures is superior in terms of resistance to budding, modulus of elasticity but also in terms of fatigue resistance.

The concept of asphalt mixture with high modulus is not a new one worldwide, the subject being analyzed by several researchers in the field. Thus, Huang et al. studied investigates the modulus properties of high-modulus asphalt mixtures (HMAMs) and their correlation with rutting resistance. Different HMAMs were tested to evaluate their rutting resistance, propose modulus evaluation indicators, and analyze the rutting resistance mechanisms of different materials used in the mixtures. The dynamic modulus test and wheel track test results indicated that the dynamic modulus of the mixtures increased with the increase of loading frequency and decreased with testing temperature. The ratio of dynamic modulus in low frequency to that in high frequency correlated well with dynamic stability under high-temperature conditions. The study provides valuable insights into evaluating and improving the rutting resistance of HMAMs, and emphasizes the significance of the dynamic modulus index in predicting pavement rutting performance based on the modulus and the improvement of pavement rutting resistance [10].

Izaks et al studied few mixes optimized for volumetric properties and evaluated through various performance tests. The results indicated that the optimized HMAMs mixes could offer high resistance to rutting and fatigue, compared to a reference mixture made with conventional bitumen and granite aggregate. The study concluded that weak Latvian dolomite can be effectively utilized in HMAMs for base and binder courses, offering a cost-effective solution for road construction [11]. Through detailed laboratory testing procedures, dynamic modulus measurements, and fatigue testing with a mechanical-computational model Hernández comprehensively analyzed the fatigue life of conventional bitumen 60/70 and high modulus bitumen 13/22, demonstrating the potential for HMAMs to significantly enhance pavement longevity, reduce maintenance needs, and improve pavement performance [12].

Another researchers, using the Witczak model, developed of a new predictive model for calculating the stiffness modulus |E*| of high-modulus asphalt mixtures (HMAMs) using the four-point bending beam test (4PB-PR). The development of the model provides a new tool for calculating stiffness modulus, contributing to the understanding and design of high-modulus asphalt mixtures [13].

The purpose of this paper, based on laboratory tests, is to highlight the importance of appropriate laboratory studies on the influence of the components on the behavior of the asphalt mixture and the need for a closer relationship between these tests and the characteristics taken in the dimensioning calculation of road structures.

2. MIX DESIGN

2.1. Materials used in the study

For the study of the behavior of asphalt mixture with high rigidity mode, 3 types of bitumen were used, namely:

- Road bitumen type 35/50
- Road bitumen type 50/70
- bitumen modified with polymers type 25/55-65

Following the tests performed to verify the characteristics of the 3 types of bitumen, it appears that they meet the requirements of the Norm AND 605 and at the same time comply with the requirements of the standards SR EN 12591 and SR EN 14023.

Following the tests performed to verify the characteristics of the natural aggregates sorts used, it appears that they meet the requirements of Norm AND 605 and at the same time comply with the requirements of the SR EN 13043 standard (table 1).

The criteria for the selection of aggregates skeleton and the proper mix design are the key elements to obtain high performance requirements of the asphalt mixture.

Table 1. Sources of aggregates used

Item No.	Material type	Source
1	Grade 0/4	Mineral Rom - Bixad Quarry
2	Grade 4/8	Mineral Rom - Bixad Quarry
3	Grade 8/16	Mineral Rom - Bixad Quarry
4	Grade 16/22,4	Mineral Rom - Bixad Quarry
5	Limestone filler	Holcim - Campulung

2.2.Particle size curve shape

This influences the compaction mode of the asphalt mixture by the fact that there may be mixtures that will segrify or mixtures that will have a proper thickening. The more numerous the contacts between the granules, the more compact and stable the road layer. The best behavior is obtained for natural aggregates with continuous grain curves. In this respect, it was sought to define an ideal grain curve, or an area within which the granulosity curve of the material is permanently located to correspond to the areas of use in the road sector

In the case study, a continuous particle size curve was used, as it can be shown in tables 2 and 3.

Table 2 Granulosity aggregates and filler

Granulosity of aggregates and filler:								
Type of aggregates	**Size**	**Site passes %**						
		0,063	0.125	2	4	8	16	22.4
Crushed stone	16-22,4mm	0.2	0.2	0.2	0.2	0.2	14.3	93.2
Crushed stone	8-16mm	0.6	0.7	1.2	1.8	9.3	94.3	100.0
Crushed stone	4-8mm	0.9	1.1	1.3	12.4	91.9	100.0	100.0
Crushed sand	0-4mm	9.8	17.1	63.9	93.1	100.0	100.0	100.0
Filer	-	76.0	92.5	100.0	100.0	100.0	100.0	100.0

Table 3 Total mixture granulosity

Granulosity of the total mixture:								
Type of aggregates/sort	**Dosage**	**Site passes in %**						
	%	**0,063**	**0.125**	**2**	**4**	**8**	**16**	**22.4**
Size 16-22,4mm	19	0.0	0.0	0.0	0.0	0.0	2.7	17.7
Size 8-16mm	25	0.2	0.2	0.3	0.5	2.3	23.6	25.0
Size 4-8mm	26	0.2	0.3	0.3	3.2	23.9	26.0	26.0
Sand 0-4mm	27	2.6	4.6	17.3	25.1	27.0	27.0	27.0
Filer	3	2.3	2.8	3.0	3.0	3.0	3.0	3.0
Total	100	5.3	7.9	20.9	31.8	56.3	82.3	98.7

Particle size area AB 22.4 Normative AND 605-2016	2	3	19	27	38	70	90
	5	8	34	43	58	86	100
Particle size zone BAD 22.4 Normative AND 605-2016	3	5	20	28	42	73	90
	7	10	35	45	61	90	100

For each type of bitumen analyzed (35/50, 50/70 and 25/55-65) a mixture with the below granulosity was made (figure 1).

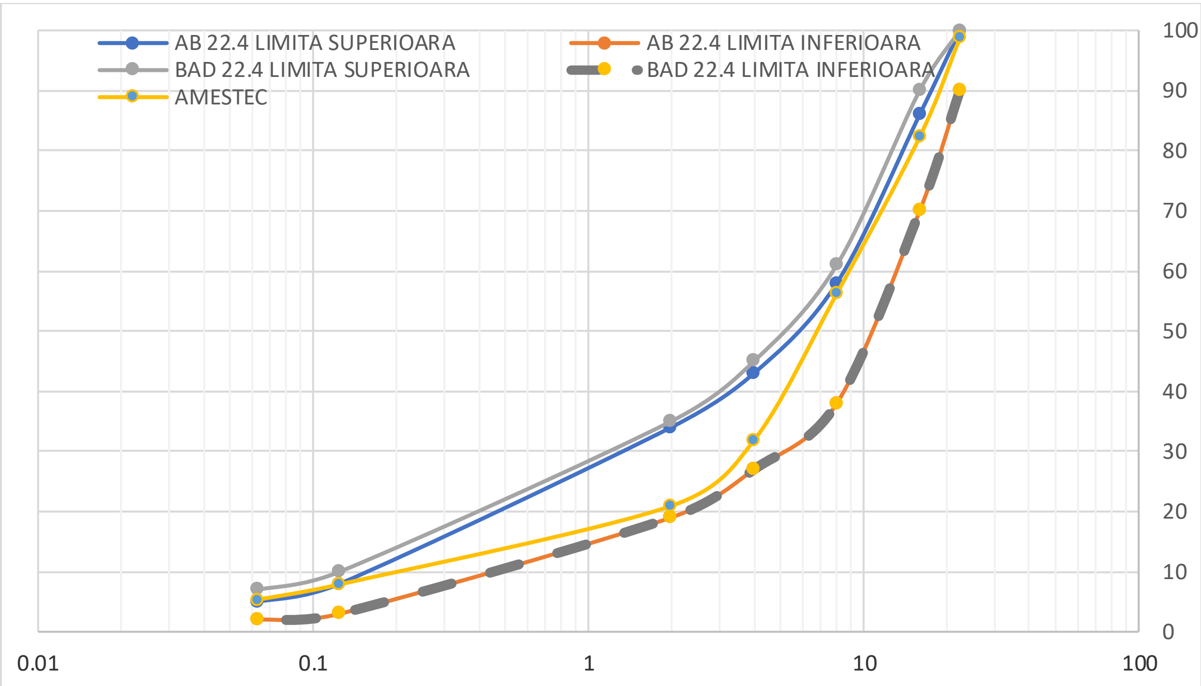

Figure 1 Graphical representation of mixture granulosity

The recommended values for bitumen content take into account an average mass by volume of aggregates of 2,650 Mg/m^3.

For other values of the volumetric mass of aggregates, the bitumen content limits are calculated by correcting for a coefficient a = 2,650/d, where d is the actual volumetric mass of the aggregates.

The bitumen content chosen to make the 3 mixtures was 4.4%, according the recommended binder content from Normative AND 605-2016.

In the case study, the specific deformation at the base of bituminous layers, the permissible tensile tension at the base of the layer of natural aggregates stabilized with hydraulic binders and the specific vertical deformation permissible at the level of the foundation earth were analyzed, using asphalt mixtures with high modulus of rigidity, using the same road structure and calculation traffic that were used for a work dimensioned based on the moduli of elasticity in PD 177.

The moduli of rigidity that were used were determined according to SR EN 12697-26, Annex C, on cylindrical specimens (IT-CY). Test temperatures were both 15°C, the reference temperature used in PD 177, and 20°C, the reference temperature used in AND 605.

For asphalt mixtures used as a bonding and base layer, the same type of asphalt mixture was used, starting from the French concept of using a single mixture for both the binder layer and the base layer. The proposed asphalt mixture can fit into the particle size curve imposed by norm AND 605 for the mixture type AB 22.4 and for the mixture type BAD 22.4. The use of this type of mixture in the pavement structure would lead to a better distribution of stresses and strains in pavement layers. The use of HMAM in the binder course should limit the effect of compressive stresses in this layer and also put a limit on deformation or rutting. The base course is subject to repeated tensile stresses which would lead to premature fatigue cracking and the use of HMAM mix in this layer would decrease significantly the risk of fatigue.

The results obtained are presented in the table 4 and graphical in figure 2, below:

Table 4 Rigidity test results

	MA Project 25/55-65	MA Project 35/50	MA Project 50/70
Stiffness [Mpa] - 20ºC	5011	6650	5456
Stiffness [Mpa] - 15ºC	6314	8012	7408

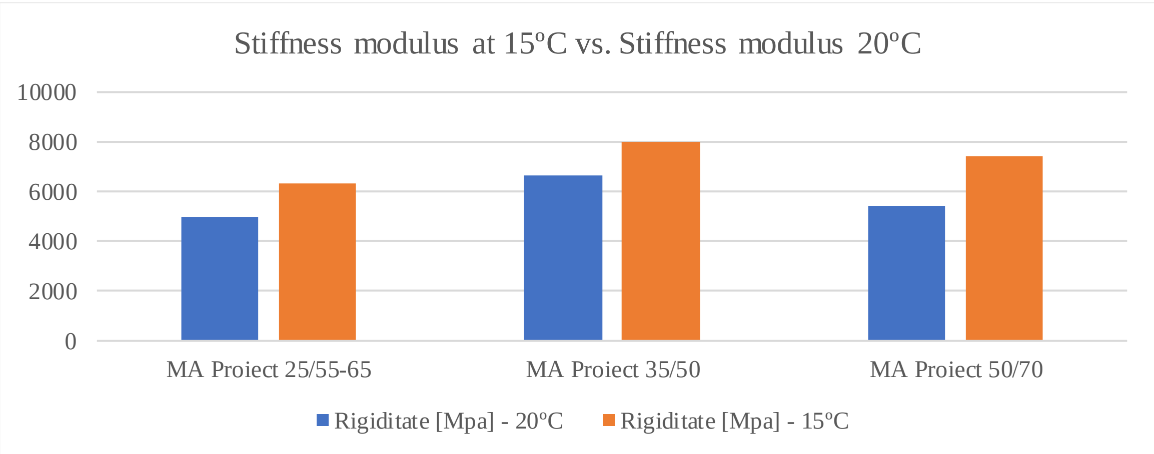

Figure 2 Graphical representation of the results obtained

A significant difference can be found between the value of the modulus of rigidity obtained at a temperature of 15 °C and the module obtained at 20 °C.

With the performance obtained regarding the modulus of rigidity at temperatures of 15°C and 20°C, several variants were made regarding the use of modules obtained by laboratory tests and a performance-based mix design approach is conducting further.

Starting from the same road structure and traffic level, it is first found that there is a difference between the values obtained by using the moduli of elasticity in PD 177 and the moduli of rigidity in AND 605.

It is also observed that there is a difference between the values obtained for modules determined at 15 °C and those determined at 20 °C using the same type of bitumen.

2.3.Analysis of results

2.3.1. Fatigue degradation rate, RDO

Table 5 The results obtained from the analysis of the road structure with the Alize program

	PD 177	AND 605	MA Proiect 25/55-65, 20°C	MA Proiect 25/55-65, 15°C	MA Proiect 35/50, 20°C	MA Proiect 35/50, 15°C	MA Proiect 50/70, 20°C	MA Proiect 50/70, 15°C
RDO	0.627	0.519	0.654	0.491	0.461	0.368	0.574	0.406

Figure 3 Centralization of RDO results

From the analysis of the fatigue degradation rate, it can be found that the specific deformation at the base of bituminous layers (ε_r) decreases when harder bitumen is used.

By far, the best results were achieved using a harder bitumen, type 35/50. This type of bitumen, mainly used in countries with similar climates, is one of the soft bitumen used in these countries to obtain mixtures with high modulus of rigidity. In these countries, bitumen type 20/30 and even 10/20 are used to obtain a high-modulus asphalt mixture.

2.3.2. Permissible horizontal tension at the base of the layer of natural aggregates stabilized with hydraulic binders

Table 6 The results obtained from the analysis of the road structure with the Alize program

	PD 177	AND 605	MA Proiect 25/55-65, 20°C	MA Proiect 25/55-65, 15°C	MA Proiect 35/50, 20°C	MA Proiect 35/50, 15°C	MA Proiect 50/70, 20°C	MA Proiect 50/70, 15°C
σr (MPa)	0.116	0.111	0.115	0.109	0.108	0.104	0.111	0.105

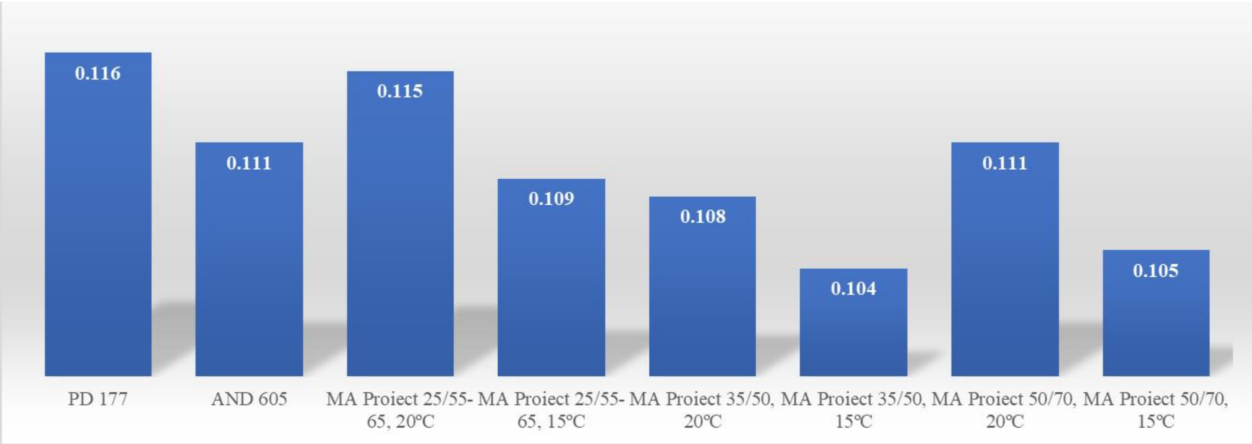

Figure 4 Centralization of σ_r results

Regarding the permissible horizontal tension at the base of the layer of natural aggregates stabilized with hydraulic binders (σ_r), it can be found that a mixture with a higher modulus of rigidity helps to lower the values obtained at this level.

The horizontal allowable tension at the base of the layer of natural aggregates stabilized with hydraulic binders (σ_r) has the same behavior as in the case of fatigue degradation rate (RDO).

2.3.3. Permissible specific vertical deflection at foundation earth level

Table 7 The results obtained from the analysis of the road structure with the Alize program

	PD 177	AND 605	MA Proiect 25/55-65, 20°C	MA Proiect 25/55-65, 15°C	MA Proiect 35/50, 20°C	MA Proiect 35/50, 15°C	MA Proiect 50/70, 20°C	MA Proiect 50/70, 15°C
εz (microdef.)	162.8	158	160.6	155.5	154.7	151.8	157.7	153.1

Figure 5 Centralization of εz results

Regarding the specific vertical deformation at the level of the foundation earth, it can be found that mixtures with high modulus help to decrease the values obtained at this level.

The specific vertical deformation at foundation earth level (ε_Z) also behaves in the same way as in the case of fatigue degradation rate (RDO) and permissible horizontal tension at the base of the layer of natural aggregates stabilized with hydraulic binders (σr), in the sense that they decrease if the mixtures used have a higher modulus of rigidity.

3. CONCLUSIONS

High-modulus asphalt mixtures help to decrease the thickness of the road structure, so significant economic advantages can be obtained, taking into account that for a road work, without art or auxiliary works, the value of the asphalt mixture has the highest proportion of the work. By decreasing the thickness of road structures, environmental benefits are also obtained given that fewer materials will be needed, such as aggregates, bitumen, and, implicitly, asphalt mixtures. By decreasing the quantities of materials used, the number of trucks needed to transport materials is also reduced. Reducing the number of trucks needed decreases traffic pressure on roads, taking into account that the volume of truck traffic is one of the criteria used to determine the millions of standard axles to which the road must be dimensioned.

The duration of execution of works will be reduced. These high-modulus mixtures adapt well to roads at risk of permanent deformation and plating, both in urban areas and on roads outside built-up areas. The use of mixtures with a high modulus of rigidity offers the possibility of reducing excavation thicknesses, an extremely profitable asset for the urban area, where problems are encountered due to municipal networks.

At the same time, there is the alternative that using the same road structure dimensioned with a mixture with normal bitumen, compared to the same structure made of asphalt mixtures with modified bitumen, there is the prospect of extending the life of the structure, given that the high moduli of rigidity decrease the specific deformation at the base of the bituminous layers (εr). This increases road life by preventing breakdowns caused by road fatigue.

From the study conducted by the EUROVIA Group on mixtures with high modulus of rigidity, the following performances were obtained:

25-30% decrease in energy and aggregates consumption;

Reducing greenhouse emissions by more than 25%.

In the manufacture of high-modulus mixtures, it is an advantage to use milled material (RAP), which, due to aging residual bitumen, will decrease the penetration of the bitumen mixture formed by the newly used bitumen and the existing bitumen from the milled asphalt mixture.

The use of asphalt mixtures with high modulus of rigidity also helps prevent permanent deformations, given that many of these types of failures come from the layers below the wearing layer.

The road structure must allow motor vehicles to circulate in the best possible conditions and distribute stresses in order to withstand without deformation the mechanical stresses caused by heavy traffic. Layers of asphalt mixtures with high modulus of rigidity are necessary for the construction of infrastructures subject to heavy and heavy traffic.

By using a single type of asphalt mixture with high modulus (asphalt mixture – project) instead of two layers of asphalt mixture (base and binder course) a significant saving can be achieved by operating a single layer with a greater thickness, but still having a smaller thickness than using two layers of asphalt mixtures (base and binder course) when the minimum thickness for a layer of AB 31,5 is 8 cm, for a layer of AB 22.4 is 6 cm, and the minimum layer thickness of BAD 22.4 cm is 5 cm.

At the same time, it is necessary to correlate the modules used to size the road structure, according to PD 177 design norm, with the modules necessary to be obtained in accordance with the AND 605 norm, normative that is used to design and verify the quality of asphalt mixtures. Until the appearance of the norm AND 605 there was a correlation between modules used for sizing road structures and modules used for designing and checking asphalt mixtures, according to SR 174-1. Currently, the values of the modules in the AND 605 norm, for technical class I-II roads, are higher than the values existing in the PD 177 design norm.

Furthermore, as demonstrated above, the values of the moduli of rigidity in the design normative PD 177 are determined at a temperature of 15°C, while the values of the modules in AND 605 are determined at a temperature of 20°C. Basically, higher performances are required in execution than those that were taken into account at the time of sizing the road structure.

We consider it important for a road structure to have a reserve on the service life at the time of design and execution, given that the perspective duration taken into account at the time of sizing is 15 years. However, from the moment of design to the moment of execution and after the expiration of the warranty period, traffic lanes may develop on the newly built, reinforced or rehabilitated road, possibly also heavy traffic, which will have a greater impact than the one that was considered at the time of design. Thus, the life of that road will decrease and new reinforcement works will be needed to ensure that traffic can be carried out in viable conditions.

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