Effect of bitumen type and polymer on physico-mechanical properties of asphalt pavement

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Abstract. Currently, worldwide, different technologies or different materials are used to increase the performance of the asphalt mix. Depending on climate and traffic conditions, each country has adopted specific solutions that improve the behaviour of asphalt pavement over time. Because each of these products has a particular effect, it is not possible to add a product to the mix to improve all of its technical features. The performance of asphalt pavement depends on the optimal selection of basic materials: natural aggregates, filler, bitumen, polymer and fiber. The aim of this paper is to investigate the relationship between the constituents of the asphalt mixture and its physico-mechanical properties. Characteristic properties of bitumen used in the mixtures were determined by conventional bitumen tests and rheological tests according to SHRP. After optimum bitumen content was determined, the influence of the polymer in the mixture was studied. SMA mixes were prepared with different penetration grades bitumen, from different sources and performance tests were conducted in order to evaluate the behaviour of the mixtures.

1. Introduction

The principles for the design and quality control of asphalt mixtures have not changed significantly over the last decades and are mainly based on the verification of the properties of the constituent materials, their proportions and the compaction. In recent years, some specifications have been supplemented with performance-based parameters. The traditional requirements have been established empirically by correlating the performances of the pavement with the design parameters. This approach is reliable when the materials used and the types of mixtures are relatively constant and sufficient evidence can be collected to correlate the empirical properties with the field performance. However, the increasing use of reclaimed asphalt pavement, warm mix technology, the use of alternative aggregates, bitumen modifiers, improved oil refining processes and other technological advances drive the asphalt mix beyond the narrow edges for which the design criteria of the empirical mixtures are true.

An ideal design of a mixture, based on performance criteria, would reflect the mix performance of the field and allow the evaluation of mixtures for a particular climate area and for a specific purpose. This would allow optimization of material selection and proportions, as well as the introduction of unconventional materials and technologies. Performance-based criteria have the potential not only to improve road characteristics and extend their lifespan, but also to improve production technologies, increase cost efficiency and minimize the footprint of asphalt and road production on the environment.
2. Literature review
Choosing the optimum binder content is very important to ensure the rutting resistance, because increasing the binder content will also increase the size of the rut [1-3]. The use of a harder binder as well as aging will reduce the rutting, but the effect is relatively smaller compared to the variation of the binder content [4-8]. These issues have already been addressed indirectly in the mix design specifications in many countries, with the use of a harder binder and limiting the maximum binder content for higher traffic volume.

The increase of the deformations is related to the decrease of the viscosity of the binder at high temperatures, which leads to a lower interconnection between the aggregates. The contribution of the mineral skeleton to the mixing behaviour becomes more significant at higher temperatures [9]. Mahboub and Little [10] found that mixtures containing less viscous bitumen are less rigid and more prone to rutting. They also recommended several types of viscous bitumen in thicker road structures and in hotter climatic areas.

Regarding the air void content in the mix, it was found that its reduction leads to an increase in the rutting resistance of the asphalt pavement. It is generally considered that the optimal percentage of air void content should be about 3%.

Based on the SHRP testing and the experience gained over time, it was found that an increase in bitumen content and a decrease in the air void content result in an increase in the fatigue resistance of the asphalt pavement. A low air void content has at least two effects that are likely to contribute to a longer fatigue life. First, because the air transmits little or no effort at all, replacing part of the volume of bitumen and aggregate voids reduces the level of loads on these components. Second, a smaller volume of air voids creates a more homogeneous bitumen-asphalt structure - one with fewer, smaller and more evenly distributed voids - which results in a lower concentration of stresses at critical solid-air interfaces. Also, it was found that the reduced porosity increases the rigidity and final strength of the asphalt mixtures [11].

Modification of bitumen with SBS significantly improves the rutting resistance of the mixtures [12-14]. The effect of the polymer depends on the type of polymer and its dosage in bitumen, as well as the penetration grade of bitumen [7]. Mixtures modified with SBS are more "forgiving" in terms of rutting with a very low air void content compared to similar unmodified mixtures [15].

3. Materials and Testing
Bitumen is obtained by vacuum distillation of crude oil. Hard bitumen is obtained by oxidation with atmospheric oxygen at high temperatures. It is used for the preparation of asphalt mixtures and has a decisive importance in their behaviour, its type being chosen according to the asphalt mix we want to prepare, more precisely the physical-mechanical characteristics envisaged for the asphalt mix.

The bitumen content of a mix is one of its most important characteristics. Using a bitumen content lower than necessary, it can result in a dry and rigid mixture, difficult to put into operation and compacted and which will be prone to cracks and other durability problems, having a lower resistance to fatigue cracking.

For this paper, a laboratory study was performed for a SMA 16 mixture, prepared with 5 types of bitumen (with different penetrations, both simple bitumen and modified bitumen, coming from two sources).

Starting from a basic recipe, mixtures prepared with different types of bitumen have been characterized by laboratory tests, with the final aim of analysing the influence of bitumen on the behaviour of the mix in the field.

Following are presented in the form of graphs the results obtained after the classical tests and those according to the SHRP methodology on the 5 bitumen used in the research work, namely: OMV
50/70 bitumen, TOTAL Azalt 50/70 bitumen, OMV PmB bitumen 45 / 80-65, TOTAL STYRELF bitumen 45 / 80-65A, OMV 70/100 bitumen.

The bitumen penetration is shown in figure 1, and the variation of the softening point and the Fraass breaking point depending on the type of bitumen studied is shown in figure 2.

SHRP methodology classifies asphalt binders into performance grade, based on the maximum and minimum temperatures taken into account when designing road structures, considered as representative temperatures, namely:
- \( T_{\text{max}} \) - the average temperature of the maximums that can appear in the road clothes during 7 consecutive hot days (° C);
- \( T_{\text{min}} \) - the minimum temperature that can be recorded during the service life (° C).

The parameters used to determine the performance grade are: stiffness modulus \( S \), slope \( m \), complex shear modulus \( G^* \) and phase angle \( \delta \) (figure 3).
The results obtained after determining the stiffness modulus as a function of temperature can be seen in figure 4.

From the results obtained by the SHRP methodology it is observed that the stiffness (S) of the modified bitumens is usually lower than that of the simple bitumens (the polymer improving the relaxation under the bitumen stress) (figure 4) and depends on the initial characteristics of the bitumen subjected to modification; thus, for the original bitumens with weak Fraass breaking points, the modifier does not bring significant improvements in the low temperature behavior. Even if the Fraass breaking point is improved by polymer modification, the temperature at which the stiffness modulus and the slope m have values corresponding to the SHRP methodology remains usually the same, the low temperature performance class being not improved. It is noted, however, that the simple bitumens crack at -12 ... -14 °C, while the modified bitumens resist up to -20 °C.

**Figure 3.** Performance grade bitumen.

**Figure 4.** Stiffness modulus.
The chemical composition and concentrations of the components of each type of bitumen studied are shown in figure 5.

![Chemical composition](image)

**Figure 5.** Chemical composition.

It is observed that the bitumens have a similar chemical composition, with a low content of saturates and high aromatics, which gives them a low colloidal instability index (0.33 ... 0.38), specific to soil type bitumens. The low saturated content is imposed by the paraffin content, which is usually over 2%. This fact correlates with the Fraass breaking point presented by this type of bitumen and which varies between $-12^\circ C$ ... $-14^\circ C$, being weaker than that of modified bitumens, which reach $-20^\circ C$.

Figure 6 shows the viscosity of the modified bitumen. It is observed that the viscosity decreases with increasing temperature. It has also been found that the modification of the bitumen with polymers considerably increases the viscosity of the bitumen (from 0.375... 0.406 Pa.s to 1.895... 1.935 Pa.s).

![Brookfield viscosity](image)

**Figure 6.** Brookfield viscosity.

Next, the curves for bulk density, maximum density and volume of voids were plotted according to the bitumen content (figure 7) to determine the optimum binder content of the asphalt mixture prepared with Suseni aggregates and TOTAL Azalt 50/70 bitumen.
The analysis of the data presented in figure 7 which contains the physical-mechanical characteristics on Marshall cylinders leads to an optimal bitumen content of 5.9% of the mass of the mixture. Then they were prepared in the laboratory with the same aggregates, filler and natural sand, preserving the same granulosity curve, asphalt mixtures with simple bitumen and modified bitumen, with different penetrations, coming from two sources. Their physico-mechanical characteristics are presented in the form of graphs in figure 8.
Figure 8. Mixture characteristics with different binder type.

Analyzing the obtained results it can be observed that the evolution of the stiffness modulus is directly influenced by the consistency of the bitumen used in the preparation of the mixture. Thus,
the mixture containing the simple bitumen OMV 70/100 with the penetration of 84 1/10 mm (soft bitumen) has a lower stiffness modulus by 50% compared to the mixture prepared with the bitumen Total 50/70 which corresponds to a lower penetration (60 1/10 mm).

In order to increase the performance of the mix, products made from the controlled combination of several plastomers were created, resulting in synthetic products. Such a product is also the Superplast product. It is added directly to the mixing plant for the preparation of the asphalt mix, does not require special equipment and technologies and does not change the production time of the mix.

Superplast is a granular product made of semi-rigid flexible polymers. Added to the asphalt mixes, it gives them a better strength and elasticity. Its effect is to increase the complex modulus, the resistance to fatigue and permanent deformations.

Further the experimental study consisted in evaluating the influence of the Superplast polymer on the characteristics of the asphalt mix. Initially, dosages were established for the two mixtures (with and without Superplast).

After the preparation of the mixture were performed the following tests: Marshall stability, bulk density, maximum density, binder drainage, air void, volume of voids filled with bitumen, and the results are presented in the following graphs in figure 9.
Then the curves for binder drainage were plotted as a function of bitumen and fiber content (figure 10) and the optimum fiber content that satisfies the requirement imposed in AND 605/2016 of maximum 0.2% for the Schellenberg test was determined from the graph. Thus we chose the optimum fiber content as 0.5% compared to the asphalt mix.

4. Conclusions

Based on the results obtained from the experimental study performed, the following can be concluded:

- the rigidity of modified bitumens is usually lower than that of simple bitumens;
- the viscosity decreases with increasing temperature;
- the modulus of rigidity depends on the consistency of the bitumen used in the preparation of the mixture (the rigidity is higher for mixtures containing bitumen with lower penetration);
- by using the Superplast polymer in the preparation of the asphalt mix, we can see an increase of Marshall stability.
5. References

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