The influence of the asphalt mixture components on asphalt mixture behavior

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Abstract: - The components of an asphalt mixture play an important role in asphalt mixture behavior during service period, so from the beginning of a design process is very important to know their influence. Nowadays we are facing of important changes in the way how bitumen and aggregates are tested and the development of new evaluation techniques for asphalt mixtures components is essential to improving our understanding of the chemical composition and behavior of different binders and aggregates in order to develop of performance based specifications.

These days there are two important problems which asphalt industry need to face up: the increasing of prices for bitumen and for good quality aggregates and the increasing of stresses in asphalt pavement due to changing of weight and loads type. The effect of these changes consist in fact that contractors have progressively shifted from recipe-based work to performance-based service.

In this paper, study consists of experimental work performed at the Technical University of Civil Engineering in Bucharest on a Romanian asphalt mixture produced with pure and polymer modified bitumen. The behavior of the mixtures is investigated by performing tests according to European Norms, such as stiffness and permanent deformation.

Key-Words: - asphalt mixtures, stiffness modulus, fatigue, permanent deformation

1 Introduction

The identification of the various types of pavement distresses allows the pavement maintenance personnel to determine what type of remedial action is necessary. Therefore early detection and repair of defects in the pavement will prevent minor distresses from developing into a pavement failure. The most important road damage mechanisms are generally categorized as:

(i) Permanent deformation (longitudinal rutting);
(ii) Fatigue cracking;
(iii) Reduced skid resistance;
(iv) Low temperature cracking;
(v) Reflection cracking;

These distresses are ultimately accountable to the reduction of remaining life of pavements and increase of the rehabilitation and maintenance cost. Each failure mechanism is affected by many factors including the roadway design and construction methods, the material properties of each constituent layer, the traffic loading and the environmental conditions throughout the service life.

2 Asphalt Mixture Components

2.1 Bitumen

Bitumen (sometimes termed as binder/asphalt) is a general description for the adhesive or glue used in asphalt pavements, either petroleum derived or naturally occurring material. The asphalt binder is what gives an asphalt pavement its flexibility, binds the aggregate together, and gives waterproofing properties to the pavement.

Even though the binder content is a key mixture design parameter, the binder grade plays a significant roll on the performance of pavement. Selecting a binder grade is essential in insuring that the asphalt will not experience significant levels of distress at the prevailing climatic condition. Asphalt binders are viscoelastic materials in nature whose resistances to deformation under loads are sensitive to loading time and temperature. Less viscous asphalts make the mixture less stiff and therefore more susceptible to irrecoverable deformations, i.e., rutting. On the other hand, if asphalt is too hard, it would be brittle at low temperatures ultimately leading to cracking under loading.
Binder behavior is at the same time dependent on loading period. The same applied loading for different periods of time will lead to different behaviors for the same binder. The dependence of binder on temperature, but also on the loading period, makes possible the interchanging of these factors. In other words, a small loading rate can be simulated with the help of high temperatures, and the high loading rate can be simulated with low temperatures.

The bitumen percentage: many researchers have concluded that exists an optimum percentage of bitumen for the life duration at fatigue and for a high rigidity module of mixtures. A small variation of the bitumen percentage of ±0.2% can change the life period with more than 100%.

Monismith [1] came up to the conclusion that the mixture with hard bitumen has a longer life period at fatigue and a smaller slope of the effort depending on the life duration at fatigue (controlled effort test, 6% binder).

Hard bitumen is better at high temperatures than soft bitumen, while at low temperatures soft binder has a better behavior. This appears in asphalt mixtures where temperature efforts grow with the temperature. The thermal efforts from an asphaltic material are higher when the bitumen is hard, then in the situation when the binder is soft.

Additives: bitumen has a low adhesion towards siliceous aggregates, and this means that in the presence of water the binder film from the aggregates can be removed. For wearing course (which apparently are impermeable) water can penetrate in three ways: through infiltration, through capillarity or water steam from air can penetrate mixture gaps and condense.

The effect of additives: Because of the hydrophilic characteristic of the aggregates, in normal conditions they have a higher affinity towards water then towards binder. The additives effect can have:
- active effect: the additives increase their contact angle between binder and aggregates, allowing the binder to cover the aggregates, even in the presence of water;
- passive effect: in time, water can detach the binder off the aggregates; additives consolidate the links between the bitumen and the aggregates and prevents this phenomena.

2.2 Polymers
Polymers modified bitumen is used in order to increase:
- elastic properties;
- the resistance to permanent deformations (rut);
- the resistance to thermal cracking and fatigue cracking;
- resistance to aging and wear resistance;
- the durability of asphaltic mixture;
- the improvement of the cohesion and adhesion towards the natural aggregate;

Depending on the purpose and on the application field, the modifiers can be:
- thermoplastic elastomers (eg: SBS or SIS), which improve the behavior at low temperatures, but also at high temperatures, ensures flexibility, deformation resistance, rigidity, durability;
- plastomers (eg: EVA), which improve the general behavior at high temperatures;
- thermopolimers – “reactive polymers” (eg: EGA).

The bitumen modified this way has improved elastic characteristics, high resistance at cold cracking, at fatigue and durability on long term; also it doesn’t have any problems regarding the preparation of binder and especially its storage.

Internationally speaking, there are two methods for modifying binder’s properties through polymers: the first method is the stiffening of binder, in order to reduce the viscoelastic properties, and the second method consists in increasing the elastic component of the binder and reducing the viscous one – this ensures a better behavior at fatigue and permanent deformations.

This area of polymers modified binder is a complex one, the improvement brought to exploitation behavior of an asphaltic mixture being dependent on binder’s rheology and also the type and quantity added of polymer. Bahia (1995) [2] studied the effect of modified binder with polymers, using scanned images with electronic microscope, and the results showed that the modified binder mixtures have a better adhesion towards aggregates, an increased binder viscosity, factors which improved the stretching resistance, but also the compressive resistance of the mixture (Fig.1).

Fig. 1 The influence of the bitumen type on rutting
2.3 Aggregates

Aggregates are the key materials used in the construction sector and the largest portion of an asphalt pavement. Aggregates are generally derived from stone minerals and sometimes further mechanically processed to suit for specific applications. Synthetic aggregates, most commonly blast furnace slag from the steel industry, slate wastes and ashes, are also used in the construction of asphalt pavements.

![Fig. 2 Aggregates main properties](image)

Mineral aggregate (predominantly of coarse aggregate) constitutes approximately 90–95% of hot-mix asphalt (HMA) by weight. Research has shown that aggregate characteristics such as particle size, shape, and texture influence the performance and serviceability of hot-mix asphalt pavement. Aggregate shape is one of the important properties that are considered in the mix design of asphalt pavements to avoid premature pavement failure. Flat and elongated particles tend to break during mixing, compaction and under traffic loading. It has been found a direct correlation between the rutting potential of HMA mixtures and the shape and texture of coarse aggregate particles. Some mixes with flaky aggregates have been found to exhibit higher fatigue life than mixes with non flaky aggregates. Mixtures made from angular aggregates (obtained by crushing) deform to a minor extent and are more stable than mixtures having the same composition and grading but made from rounded aggregates (river gravel).

The percentage of crushed coarse particles has a significant effect on laboratory permanent deformation properties. As the percentage of crushed coarse particles decreased, the rutting potential of the HMA mixtures increased. It is emphasized in literature that cubical, rough-textured aggregates have better interlocking mechanisms; reduce the potential for rutting and more resistant to the shearing action of traffic than rounded and smooth-textured aggregates.

Some researchers indicated that dense aggregate properties and gradations are desirable to mitigate the potential effects of rutting of asphalt concrete pavement. When properly compacted, mixtures with dense or continuous aggregate gradations have fewer voids and more contact points between particles than open or gap-graded mixtures. For example, a gap-graded mixture exhibits more deformation than a continuously graded mixture due to less aggregate interlock in the gap-graded mixture. Aggregate interlock becomes more important at higher temperatures; gap-graded mixtures may be even more susceptible to rutting at higher temperatures. As well as, the use of larger maximum aggregate size (about two-thirds of layer thickness) would be beneficial in reducing the rutting propensity of mixtures subjected to high tire pressures.

For better rutting resistance the surface texture of the aggregate plays an extremely important role. Particularly in thicker asphalt-bound layers and hot climates, a rough surface texture is required.

2.3.1 Granularity and methods of identifying the granulometric composition

One of the key properties of aggregates which influences the quality of asphaltic mixtures is granularity. This is graphically represented through a granulometric curve, which has on vertical the passing from the sieves in percentage (arithmetic scale), while on the horizontal are represented the sizes of the particles (logarithmic scale).

For asphalt mixtures there is a general idea that a curve is balanced, continue and that will give the best resistances at permanent deformations for most of the types and the quality of aggregates (Fig. 3).

![Fig.3. Example of granulometric curve](image)
influences the properties of asphaltic mixtures, such as: stability, durability, permeability, fatigue resistance.

2.4 Filler

Adding filler to the mixture, air voids volume decreases, the rigidity of the mixture increases and influences the optimum bitumen percentage for the mixture.

Pell showed that there is an optimum percentage of filler for the maximum life duration at fatigue, and the filler volume is very important in the minimization of the air voids volume in aggregates. The maximum life duration at fatigue appears at different percentages in weight of filler, but the same percentages in filler volumes for three types of filler.

Scientific literature pins up an optimum percentage, in weight, of filler of 5-11%.

Filler increases the viscosity of too fluid binders, and also of all the binders heated up at high temperatures. This is the main reason why in some asphaltic mixtures, a bigger quantity of bitumen can be used to increase the cohesion and the impermeability, without the danger for the mixture to become unstable or to appear binder stains at the asphaltic mixture surface;

- shortens the drying period of fluid binders and shrinks the aging speed of all binders, because it absorbs or give away, from case to case, the most volatile oils from bitumen’s composition;
- increases the compactness and mixtures resistance at the action of water;
- reduces the susceptibility of mixtures, shrinking the viscosity variations reported to temperature;
- having a large specific surface, the filler has an appreciable quantity of free superficial energy, which manifests through an increase of the adsorption capacity and of the bitumen adhesion level towards aggregates. Also, because of the large number of stones, appears an increase of the adherence and cohesion, and so of the mixtures resistance. The same causes increase also the thermal stability of the binder.

As a summary of the statements above, it can be pointed out that the filler has a favorable action towards bitumen’s characteristics, improving plasticity and having an important role in preventing bitumen’s aging, with positive effects on the behavior in exploitation of asphaltic mixtures.

3 Laboratory testing regarding the influence of the bitumen type from the asphaltic mixture

In Roads Laboratory of Technical University of Civil Engineering Bucharest were conducted studies to point out the influence of asphalt mixture components on asphalt mixture properties. From all components the study focused on the bitumen percentage influence on the asphalt mixture stiffness, during the design of a mixture recipe MAMR 16. Laboratory tests were made regarding indirect tensile test on cylindrical samples, at 15°C and 124 ms loading period with different percentages of bitumen – OMV 25/55 – 65 PMB STARFALT.

The behavior of laboratory designed asphalt mixture continued with the study regarding modified bitumen, using the same mineral body and without modifying the bitumen percentage, as it can be noticed in the figures below. In tables 1 and 2 are presented the types of bitumen that were used (3 polymers modified bitumen and on pure), and also the values that were obtained during the four points bending test on prismatic samples (4PB – PR) and during the trial of indirect tension on cylindrical samples (IT – CY).

Table 1. Rrigidity module at 4PB-PR related to the type of used bitumen

<table>
<thead>
<tr>
<th>Bitumen type</th>
<th>Penetration at 25°C, 1/10mm</th>
<th>Rigidity module, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMV 10/40 PMB STAR FALT</td>
<td>18</td>
<td>17276</td>
</tr>
<tr>
<td>OMV 25/55 PMB STAR FALT</td>
<td>35</td>
<td>12430</td>
</tr>
<tr>
<td>OMV 45/80 PMB STAR FALT</td>
<td>68</td>
<td>8513</td>
</tr>
<tr>
<td>OMV 50/70 STAR SSENBAU BITUMEN</td>
<td>64</td>
<td>13946</td>
</tr>
</tbody>
</table>
The stiffness modulus was measured at 15ºC depending on the type of bitumen for samples tried at four points bending (4PB-PR), respecting the conditions established by SR EN 12697-20 and SR EN 12697-26, realized on asphaltic mixture with the same bitumen percentage but with different types of bitumen. After these trials, the following conclusions were pinned up:

- a decrease with ≈ 28% of the stiffness modulus for an increase of the bitumen penetration PMB with ≈ 48% (from 18 to 35 1/10 mm);
- an increase with ≈ 40% of the stiffness modulus for the pure bitumen 64 pen. comparing to the PMB bitumen 68 pen. (close penetrations);
- an increase with ≈ 10% of the stiffness modulus for the pure bitumen 64 pen. comparing to the PMB bitumen 35 pen. (closed values for rigidity modules).

The stiffness modulus was measured at 15ºC depending on the type of bitumen for cylindrical samples made at gyrocompactor and tried at indirect tension (IT-CY), respecting the conditions established by SR EN 12697-20 and SR EN 12697-26, realized on asphaltic mixture with the same bitumen percentage but with different types of bitumen. After these trials, the following conclusions were pinned up:

- a decrease with ≈ 41% of the stiffness modulus for an increase of the bitumen penetration PMB with ≈ 48% (from 18 to 35 1/10 mm);
- a decrease with ≈ 46% of the stiffness modulus for an increase of the bitumen penetration PMB with ≈ 73% (from 18 to 68 1/10 mm);
- an increase with ≈ 16% of the stiffness modulus for the pure bitumen 64 pen. comparing to the PMB bitumen 68 pen. (closed penetrations);
- an increase with ≈ 8% of the stiffness modulus for the pure bitumen 64 pen. comparing to the PMB bitumen 35 pen. (closed values for rigidity modules).

Another study realized in the Road Laboratory in the Faculty of Railways, Roads and Bridges, consisting in the evaluation of the behavior at permanent deformations of two mixtures: MAMR 16 and MASF 16. Each of them has three types of bitumen, noted from A to C, according to table 3. The two mixtures were designed in the laboratory with bitumen type C. Two of three types of bitumen are with polymers modified bitumen (A and C) and type B is unmodified bitumen.

<table>
<thead>
<tr>
<th>Type of bitumen</th>
<th>Penetration at 25ºC, 1/10mm</th>
<th>Stiffness modulus, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMV 10/40 PMB STAR FALT</td>
<td>18</td>
<td>12232</td>
</tr>
<tr>
<td>OMV 25/55 PMB STAR FALT</td>
<td>35</td>
<td>7144</td>
</tr>
<tr>
<td>OMV 45/80 PMB STAR FALT</td>
<td>68</td>
<td>6548</td>
</tr>
<tr>
<td>OMV 50/70 STAR SSENBAU</td>
<td>64</td>
<td>7752</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Bitumen A (Pmb)</th>
<th>Bitumen B</th>
<th>Bitumen C (Pmb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25ºC (0.1mm)</td>
<td>68</td>
<td>64</td>
<td>35</td>
</tr>
<tr>
<td>Softening point R&amp;B (ºC)</td>
<td>83</td>
<td>51</td>
<td>81</td>
</tr>
<tr>
<td>Ductility at 25ºC, cm</td>
<td>92</td>
<td>&gt;100</td>
<td>95</td>
</tr>
</tbody>
</table>
The mixtures were tried at triaxial cyclic loads according to SR EN 12697-25 – Method B at 50°C, 300 kPa loading type axial block and 0.8 bar lateral fretting pressure. The results are presented in the following figures:

![Fig.2. Creep curves for the mixture MAMR16 depending on the type of bitumen](image1)

![Fig.3. Creep curves for the mixture MASF16 depending on the type of bitumen](image2)

![Fig.4. Creep modulus curves for MAMR16 depending on the type of bitumen](image3)

![Fig.5. Creep modulus curves for MASF16 depending on the type of bitumen](image4)

### 4 Conclusions

Many factors influence the capacity of the asphaltic mixture to fulfill the structural requirements. The composition of the mixture, the laying mode, the properties of the composing materials and the use of additive play an important role regarding the final properties of a mixture. It is also interesting to observe the interaction between designing the recipe of the mixture and designing the road structure, in order to come up to financially efficient solutions.

Although important progress has been recorded regarding the understanding of the behavior of asphaltic mixtures and the factors which affect their performance, there are still many studies that needs to be done.

The factors involved in designing road structures can be divided into four larger groups:
- road traffic;
- climatic conditions for the area of the road;
- the foundation ground;
- road construction materials used in the road layers and the quality of execution.

Regarding the degradations which are currently found on roads, the following conclusions can be highlighted:

- from the point of view of permanent deformations phenomena, the bitumen has an important role, reason why it is recommended to use bitumen as rough as it can, but elastic enough; this makes the polymers modified bitumen be used more often. The aggregates used in an asphaltic mixture must ensure the existence of a strong mineral body, with a strong clenching between aggregates and which behaves like a big, elastic “stone”;
- from the point of view of the behavior of road structures regarding fatigue cracking, the use of flexible materials is very important, where the efforts and deformations are maintained at a low level. Although apparently the more rigid materials are not fit to combat the fatigue cracking phenomena from asphaltic mixtures, an exception was found when their thickness is big enough and the foundation layers permits only small deflections;
- for the study of the behavior at low temperatures cracking, the accent must be on the evaluation of the behavior of mixtures in laboratory, at low temperatures – the determination of the stiffness modulus at low temperatures and small loading frequencies (high loading time).

The quality of the materials used to obtain an asphaltic mixture play an important role in the future behavior during exploitation of the mixture.
This is the main reason why it is recommended to use aggregates with high mechanic resistance, bitumen with low susceptibility at temperature variations, an optimum filler percentage to obtain the bituminous mastic.

The studies made on polymers modified bitumen drawn to the conclusion that the presence of polymers increase the life duration of the road structure and also increase the resistance to rutting. Still, their use in flexible road structures need a better understanding of their effects on physical, chemical and rheological properties of modified bitumen.

References: