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INVESTIGATION OF THE ENVIRONMENTAL DEGRADATION OF ASPHALT PAVEMENT MIXTURES

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Abstract

The complex factors during the asphalt production pr °Cess and subsequent traffic loading, climatic and weather conditions lead to a decrease in durability of asphalt thereby reducing pavement surface service life. The physical and mechanical properties of asphalts change over time and are different than at the beginning. The paper f °Cuses on the laboratory research on effect of thermo-oxidative aging (short term and long term), ultraviolet radiation and water on stiffness and indirect tensile strength of asphalt mixtures. Experimental measurements were performed with different asphalts in terms of mix type (asphalt concrete AC, stone mastic asphalt SMA) and composition (paving grade bitumen 50/70, polymer modified bitumen PMB45/80-75, coarse aggregate andesite and granodiorite). The stiffness modulus at different temperatures (10, 20 and 30 °C) using the indirect tension method and indirect tensile strength have been evaluated in relation to the degree of aging, water and UV radiation. The experimental analysis showed a significant increase in the stiffness of polymer-modified asphalt with increasing aging intensity. Exposure to ultraviolet radiation adds to an increase of 35 to 40% in stiffness for unaged PMB asphalt and 12 to 17% for short-term aged mixtures. Accelerated water conditioning reduced the indirect tensile strength of asphalt by an average of 9%, significant in long-term aged samples using the loose mixture method (9 to 17%). The indirect tensile strengths for dry and wet conditioning showed greater changes due to the degree of aging. An understanding of the changes in asphalt properties during design allows for predicting asphalt surface behaviour after a period of use.

Keywords: asphalt, oxidative aging, UV radiance, stiffness, strength

1 Introduction

Long-term studies of asphalt surfaces have shown that to achieve design life, it is important to resist the environmental effects to which it is exposed so that there are no significant changes in their properties. Building materials in general, as well as structures, should be designed for the longest possible service life and durability. Asphalt mixtures in the wearing course of road pavements should retain the required technical and serviceability characteristics, sufficient stiffness and resistance to permanent deformation, ductility to frost and fatigue cracking, and the ability to drain using materials ensuring skid resistance properties. In addition to the stress effects from traffic loads, there are climatic and weather environmental influences, in particular, the high temperatures in summer and low temperatures in the winter period, solar radiation, humidity, snow and water precipitation, and others [1, 2]. All these effects cause a gradual degradation of the asphalt layer, especially on the road pavement surface, requiring maintenance and repair interventions of the pavement layers.

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Therefore, some of these effects are considered in the asphalt mixtures design and their impact is assessed during the design pr °Cess.

The bitumen binder, as a component of any asphalt mixture, is more susceptible to the effects of degradation than aggregates. The high temperatures and air oxygen cause the evaporating of the light fractions from the bitumen and chemical changes (increase in sulfoxide and ketone group concentrations, decrease in the proportion of aromatic fractions of the bitumen and increase in resins and asphaltenes fractions), which are reflected by changes in penetration, an increase in the softening point and viscosity and changes in rheology properties [3].

Thermo-oxidative ageing is most significant in bitumen. Oxidation is the main pr °Cess of ageing mechanisms, which is an irreversible phenomenon that can change the chemical composition of bitumen. The components of the bitumen oxidize to form heavier molecules, increasing stiffness and decreasing flexibility. In the pr °Cess of asphalt production at elevated temperatures, the hydr °Carbon molecules are split to an increased extent and the light oil fraction is evaporated, resulting in weight loss. Therefore, a weight change is observed after the RTFOT test.

The ageing of bituminous binder results in changes in its chemical composition, which is expressed by the proportion of chemically and structurally related compounds, namely the asphaltenes and saturated hydr °Carbons, aromatic compounds and resins (SARA analysis). This molecular arrangement reduces the fluidity of the bitumen, increases the viscosity and changes the rheological properties of the bitumen and contributes significantly to the service performance of the asphalt mixture/layer in the pavement.

It is observed that ageing pr °Cesses are affecting the bituminous binder. Extensive measurements and evaluations of the effect of ageing on physical and rheological properties as well as on composition (SARA and FTIR analyses) have been carried out up to now [4-6]. However, in an asphalt mixture, aggregate particles are coated with bitumen, and there are physical and chemical bonds between them. Therefore, we f °Cused on the research on the ageing effect on asphalt mixtures.

In our research, we investigated the possibility of simulating degradation factors in a laboratory environment, and what effect they have on the strength and deformation properties of asphalt mixtures used in wearing courses of pavements.

2 Experimental

2.1 Materials

To determine the effect of degradation factors on the properties of asphalt surfaces, asphalt mixtures standardly used in wearing courses of road pavements were selected for experimental works. The asphalt mixtures studied were asphalt concrete AC with PG bitumen 50/70, asphalt AC with bitumen PMB 45/80-75 (andesite coarse aggregate, limestone fine aggregate), asphalt SMA with PMB (melaphyre porphyry coarse aggregate, dolomite fine aggregate and pelletized fibres Viatop 66), asphalt AC with PMB 45/80-75 and 10% of R-material (granodiorite coarse aggregate, limestone fine aggregate, adhesion additive Wetfix BE). All mixtures are designed and produced in the plants. The gradations of the tested asphalt mixtures are shown in Fig. 1.

Mixtures were designed to meet the requirements valid for the Slovak Republic, minimum bitumen content, air void content (2.5 to 4.5 %), rutting resistance (PRDair max 5.0 %, WTSair max 0.10 mm/10^3 cycles), water sensitivity (ITS ratio min 80 %).

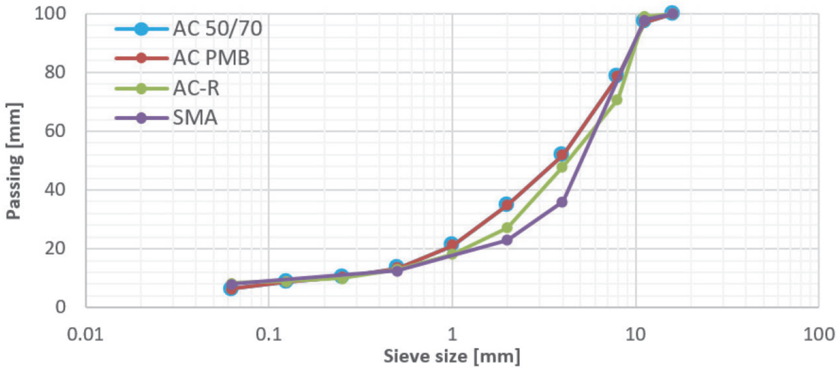


Figure 1 The gradation of tested asphalt mixtures

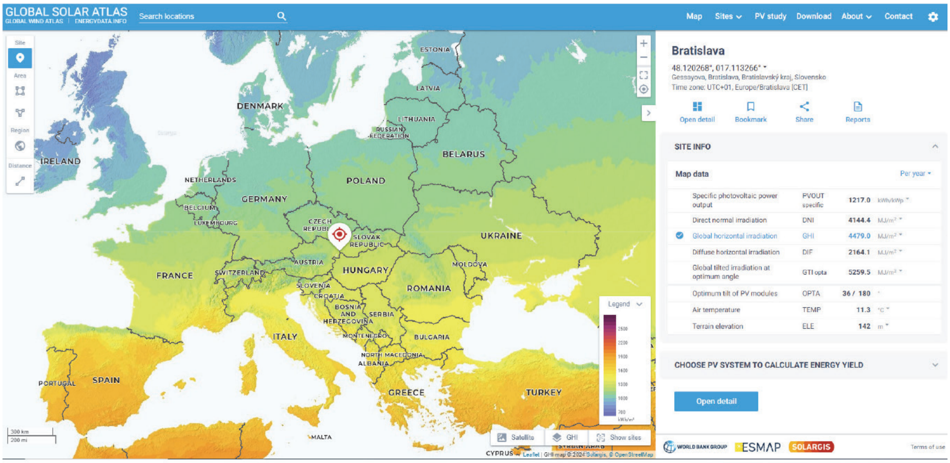
2.2 Methods

For the research on the environmental degradation of asphalt mixtures were identified the thermo-oxidation effect °Ccurring during production, delivery and placement of the asphalt mixture (short-term ageing), the effect of oxidation during the service life of the asphalt layer in the pavement in service (long-term ageing), the effect of humidity and the effect of UV radiation on the pavement in service.

Short-term owen ageing (STOA) was applied to a loosely spread asphalt mixture at a thickness of 25±5 mm. The ageing was performed in a climate-controlled chamber with air ventilation for 4h±10 min at a temperature of 135±1 °C [7, 8]. The aged mixture was compacted into the cylindrical test specimens with an impact compactor to determine the mixture characteristics and a part was intended for long-term aging.

After STOA the asphalt mixture was transferred to a perforated plate in a layer thickness of approximately 25±5 mm and placed in a tempered test chamber heated to 80±1 °C with air circulation for 96±0.5 h for long-term owen ageing of the mixture (LTOA-1) [8]. To ensure uniform ageing and to prevent segregation of the mixture, it was necessary to mix the loosely spread mixture at regular intervals (every 48 h). After the prescribed time the compacted test specimens were produced. The second option for conditioning asphalt mixtures to ageing is the specimen production from the mixture after STOA and conditioning the compacted specimens in a thermal chamber at 85±3°C and allowing oxidation ageing for 120 h (LTOA-2). To observe the water effect, specimens were saturated and exposed to water at a temperature of 40±1 °C for 68 h to 72 h time.

Un-aged and long-term aged asphalt mixtures were exposed to UV radiance in an Atlas Sunset XXL experimental conditioning chamber (Fig. 3) with three air-cooled xenon lamps of 1700 W and a radiation exposed area of 3000 cm^2. To determine the exposure, the global radiation value represented by the total solar radiation incident per unit area, is used. The annual solar radiation equivalent for the Slovak Republic ranges from 3700 to 4300 MJm^{-2} (Fig. 2). Of the total solar radiation energy, the part (6%) corresponding to the ultraviolet radiance of 300 and 400 nm and correction of 67% for the summer period are considered. The test specimens were exposed to UV radiance in 6-hour cycles (5h radiance period, 1 h rest period) at the temperature of 60 °C BST (Black Standard Temperature). The total UV exposure time is designed for 600 h [9].



Bratislava

48.120268°, 017.113266°
Gessayova, Bratislava, Bratislavský kraj, Slovensko
Time zone: UTC+01, Europe/Bratislava [CET]

SITE INFO

Map data — Per year

	Specific photovoltaic power output	PVOUT specific	1217.0	kWh/kWp
	Direct normal irradiation	DNI	4144.4	MJ/m²
✓	Global horizontal irradiation	GHI	4479.0	MJ/m²
	Diffuse horizontal irradiation	DIF	2164.1	MJ/m²
	Global tilted irradiation at optimum angle	GTI opta	5259.5	MJ/m²
	Optimum tilt of PV modules	OPTA	36 / 180	°
	Air temperature	TEMP	11.3	°C
	Terrain elevation	ELE	142	m

CHOOSE PV SYSTEM TO CALCULATE ENERGY YIELD

Figure 2 The annual equivalent of solar radiation

Figure 3 Atlas Sunset XXL solar conditioning unit (left), configuration for stiffness modulus measurement (right)

To determine the degradation effects on the asphalt mixture, changes in the asphalt mixture properties were monitored. The stiffness and indirect tensile strength of the asphalt mixture were verified.

The stiffness modulus was determined using the indirect tension method IT-CY [10] in DYNA-PAVE 78-B7015 device (Fig. 3) at different temperatures of 10, 20 and 30 °C. A minimum of 4 specimens of each type of asphalt mixture were evaluated. The loading system applied the repeated loading pulses in a half-sine shape with 124±4 ms load rise time, a horizontal deformation of 5 μm and a pulse interval of 3 s. This vertical load produces vertical compression and horizontal tension stresses in the test specimen.

The indirect tension strength (ITS) of the asphalt mixtures was determined as the maximum tension stress of the specimen loaded on a diametrically placed specimen at the specified test temperature and press rate until it breaks. The same pr °Cedure was followed for the determination of the indirect tension strength of the water-conditioned specimens [11].

3 Results and analyse

The stiffness modulus of asphalt mixtures was determined at temperatures 10, 20 and 30 °C. At least 4 samples from each mixture were analysed and the homogeneity assessment of the data showed that the results were homogeneous and could be evaluated. The results showed (Fig. 4) that the highest values were AC 50/70 and AC with R-material content mixtures. As the test temperature increases, the values of the stiffness modulus of the mixtures become equal.

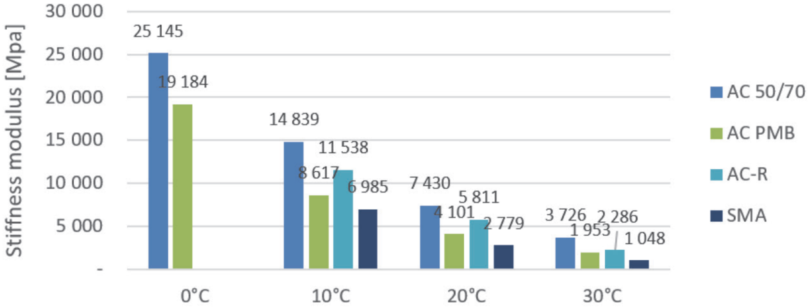


Figure 4 Results of stiffness modulus of tested asphalt specimens

For long-term ageing, where loose mixtures were subjected to oxidative ageing for 96 hours at 80 °C, the stiffness modulus of the mixtures increased by 31.2% on average, most for the AC PMB mixture (41.1% to 83.1% depending on test temperature) and least for the AC 50/70 mixture (8.6% to 25.1%). The AC 50/70 and AC PMB mixtures were also laboratory aged for a prolonged time of 120h in the form of compacted specimens. However, the results showed that this form of ageing is less intensive for the mixtures, as all tested specimens correspond to standard compacted mixtures with an air void content of 2.5 to 4.5%, which prevents the penetration of hot air into the inside of the specimen.

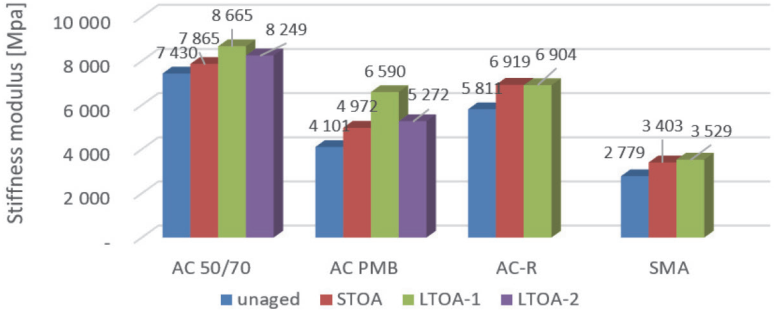


Figure 5 Stiffness modulus of aged asphalt mixtures at a temperature of 20 °C

In addition to the stiffness modulus, the indirect tensile strength of the mixtures was also determined. The strengths of the tested specimens are shown in Fig. 6.The increase in stiffness was also evident in the ITSdry values, although the increase in strength was less by an average of 1.4% for short-term aged mixture specimens and by 8.0% for long-term aged mixture specimens.

The effect of water caused a 7.5% decrease in the strength of mixture specimens (Fig. 6). On the specimens that were also exposed to the effects of short- and long-term ageing, the strength decreased by 10.5% (the AC-R mixture by 20.8% the most, the SMA mixture by 0.9% the least).

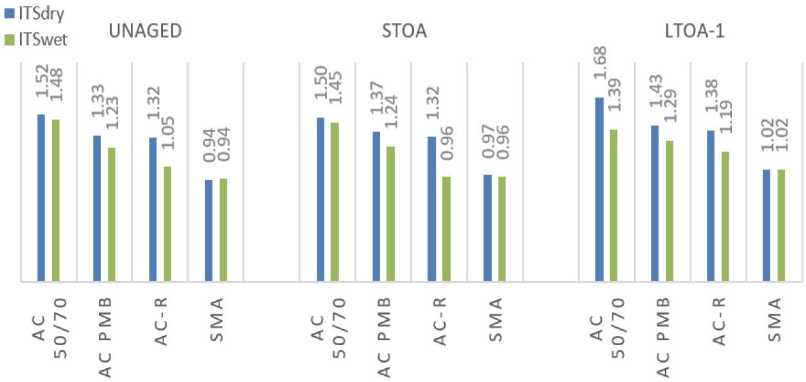


Figure 6 Indirect tension strength of dry and wet specimens of unaged and aged tested mixtures

In addition to oxidation, temperatures and water, the mixtures in road pavement constructions in service are also exposed to solar radiation. It is considered that the UV as a component of solar radiation affects the bitumen binder. To determine the effect of UV radiation, the specimens of unaged mixtures and specimens of long-term aged mixtures (LTOA-1 and LTOA-2) have been loaded in the conditioning chamber Atlas Sunset XXL. The results of stiffness modulus after 600 h of UV exposure are shown in Fig. 7.

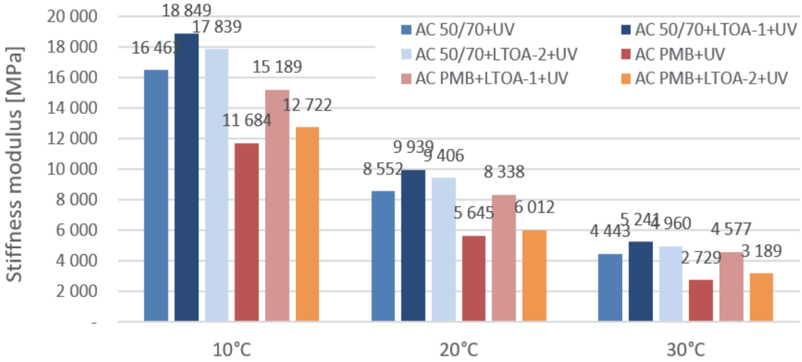


Figure 7 Effect of UV radiation exposure on stiffness of tested asphalt mixtures

The average increase in stiffness modulus was 26.4% for the unaged mixture specimens and long-term oxidative aged specimens 20.6% (LTOA-1), resp. 15.5% (LTOA-2). If we observe the effect of thermo-oxidative ageing and UV radiance on the mixture, then this combined effect was 69.2% (LTOA-1+UV) and 39.6% (LTOA-2+UV) respectively. In general, a greater effect was observed on the AC PMB mixture properties than on the AC 50/70 mixture.

4 Conclusions

The objective of the research presented in this paper was to determine the effect of environmental degradation on the stiffness modulus and strength characteristics of asphalts. Of the factors investigated, thermo-oxidative ageing, UV exposure and water, it was found that the complex of factors during asphalt production and service pr °Cesses had a significant effect on the changes in the stiffness modulus. The modulus values of standard asphalts (AC with paving grade and polymer-modified bitumen, SMA asphalt) increased by 69.2% (LTOA-1) and 39.6% (LTOA-2) when thermo-oxidative ageing was combined with UV radiation, respectively, the strength did not change that significantly (5 to 8%).

Accelerated water conditioning reduced the indirect tensile strength of asphalts by an average of 9%, significant in long-term aged samples (9 to 17%). The experimental analysis showed a significant increase in the stiffness of polymer-modified asphalt with increasing ageing intensity. An understanding of the changes in asphalt properties during design allows for predicting asphalt surface behaviour after a period of use.

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