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The Influence of Crumb Rubber on Modified Bitumen Properties

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Abstract. Rubber derived from grinding of recycled cars and trucks tyres may be successfully used as a bitumen modifier. Number of researches reported sufficient characteristics of rubber modified asphalt binders or modified asphalt mixes in terms of improved permanent deformation and fatigue cracking. The behavior of crumb rubber asphalt binders depends on several factors, such as modification method, rubber content and size, modification temperature, mixing speed and time applied during the digestion process. The aim of this study is to evaluate the effect of crumb rubber amount and type on modified bitumen low and high temperature properties. This paper presents results of unmodified bitumen, crumb rubber crumb rubber and polymer modified bitumen. Low and high temperature properties have been evaluated using bending beam rheometer and dynamic shear rheometer. Moreover, softening point and viscosity tests have been performed. The study results revealed that crumb rubber modified bitumen performed better than pure bitumen and similarly to polymer modified bitumen.

Keywords: crumb rubber, modified bitumen, rubber modified bitumen, permanent deformation, low temperature performance.

Conference topic: Roads and railways.

Introduction

In recent years, the major problems of road maintenance and condition have been related to an increase in a number of transportations by heavy vehicles and insufficient financing allocated for the road sector and the required road maintenance and repair programs (Žiliūtė *et al.* 2010). The most often and negative type of pavement distress is rutting. It significantly depends on type of pavement structure, kind and quality of materials used for different types of structure layers, also pavement construction techniques and quality (Vaitkus *et al.* 2013). Moreove, environmental conditions are very important for asphalt pavement behaviour – bitumen is known as brittle in cold environments and soft in hot environments. As a pavement material, it is characterized with a number of failures represented by the low temperature cracking, fatigue cracking, and the permanent deformations at high temperature (Cong *et al.* 2013). In order to prevent asphalt pavement from failures, scientists suggest estimate pavements' loading conditions, environmental/climate conditions, design materials at the designing stage. Desing materials as high modulus asphalt mixes with polymer modified bitumen could be a proper example of failures preventive solution. Additionally, there is suggested to apply continuously monitoring of different pavement structures performance and to elaborate on the most suitable and economically effective pavement structures (Vaitkus *et al.* 2014). Modification of bitumen is a very common these days' practice in order to improve its physical properties and performance. Modification of bitumen decreases its temperature susceptibility and this enables asphalt to withstand more load and more severe environments (Ghavibazoo *et al.* 2013). However, modification of bitumen is relatively expensive procedure. Considering these facts, less expensive modification technologies or modificators should be used.

Dramatic growth in number of end-of-life tires around the globe was recorded due to increasing number of vehicles. According to European Tyre and Rubber Manufacturers' Association (ETRMA), the EU end-of-life tyre arisings was approximately 3.5 million in 2013. Fortunately, 96% of it were recovered and recycled (ETRMA 2015). One of the most successful application of end-of-life tires is the use in road pavements (Lo Presti *et al.* 2013). Incorporation of crumb rubber in asphalt mixtures has been a major advancement in the using recycled materials in asphalt pavements. Tyres contain some of the polymeric components that have been used to modify the asphalt binders for decades, but in a solid form (Zeinali *et al.* 2014). The use of crumb rubber in asphalt pavements has shown promising results in previous studies (Shafabakhsh *et al.* 2014; Moreno *et al.* 2013; Hossain *et al.* 2016; Ghavibazoo, Abdelrahman 2014). Considering facts, that crumb rubber modified bitumen performance mainly depends on processing conditions, there are still open questions related with modifying temperature, interaction time, crumb rubber type and amount (Lo Presti *et al.* 2012; Jeong *et al.* 2010; Willis *et al.* 2013; Wang *et al.* 2013).

The aim of this study is to evaluate the effect of crumb rubber and its amount on modified bitumen low and high temperatures performance using conventional and performance based test methods.

Test methods and materials

Materials

Penetration-grade bitumen 50/70 was used as neat bitumen to prepare all the experimental mixes. A powdered waste rubber (≤0.6 mm), derived from discarded tires with all metallic and textile contaminants removed, was used as a modifying agent. Crumb rubber modified bitumen was pre-processed by mixing crumb tire rubber (7% and 10%) with neat bitumen, using a high shear mixer Silverson L5M-A with Duplex assembly (USA). Processing was carried out in a aluminium tank with aluminium foil lid for minimizing primary aging.

Test methods

The conventional physical properties of crumb rubber modified bitumen, including penetration at 25 °C, softening point and rotational viscosity at 135 °C, were tested in accordance with standards EN 1426, EN 1427 and EN 13302 respectively.

A bending beams rheometer (BBR, Coesfield Instrument Company) was used to peform low temperature creep tests according to standard EN 14771. The asphalt binder beams (127×12.7×6.4 mm) were prepared in an aluminum mold. In preparation, the asphalt binder was heated to a fluid condition, poured into the mold and allowed to cool down at room temperature for approximately 45 min. The surplus of bitumen was trimmed with hot knife. After that, the sample was cooled in the refrigerator for 5 min and demolded. Sample beams were submerged in an ethanol bath with a constant temperature of –18 and –24 °C. After 60 min storage, the rectangular beam was placed on two stainless steel supports (102 mm apart) and loaded by 100 g. The deflection of the center point was measured continuously during all test procedure. The creep stiffness (S) and creep rate (m) of the binders were determined at loading times 60 s.

Dynamic shear properties were measured with dynamic shear rheometer (MCR301, Anton Paar Co. Ltd. of Austria) in a parallel plate configuration. Rheological tests were performed under controlled strain condition. The principal rheological parameters obtained from the DSR were complex modulus (G^*) and the phase angle (δ). G^* is defined as the ratio of maximum shear stress to maximum strain and provides a measure of the total resistance to deformation. The δ is the phase shift between the applied stress and strain responses during a test and is a measure of the viscoelastic balance of the material behavior. Temperature sweeps (from 58 to 76 °C) were applied at a fixed frequency of 10 rad/s. The plate used for temperature sweep test was 25 mm in diameter and the gap between the parallel plates was 1 mm.

Experimental research

The aim of this research was to determine the influence of the crumb rubber and its amount on performance of modified bitumen in both high and low temperature conditions. The performance of the modified bitumen was evaluated in the laboratory at climate conditions those usually encountered in actual applications. To evaluate influence of crumb rubber amount on modified bitumen performance, there were selected two different amounts of rubber (7 and 10%). These percentages of crumb rubber were chosen according to literature – it is stated that from 5% to 15% of crumb rubber (or even more) can be used, but in the most of conducted researches were used ≥10% of crumb rubber. Considering these facts, there is still open question of ≤10% crumb rubber usage for bitumen modifying. To compare the performance of crumb rubber modified bitumen and polymer bitumen, usual polymer modified bitumen PMB 25/55-60 was selected. The flowchart of experimental research is given in Figure 1.

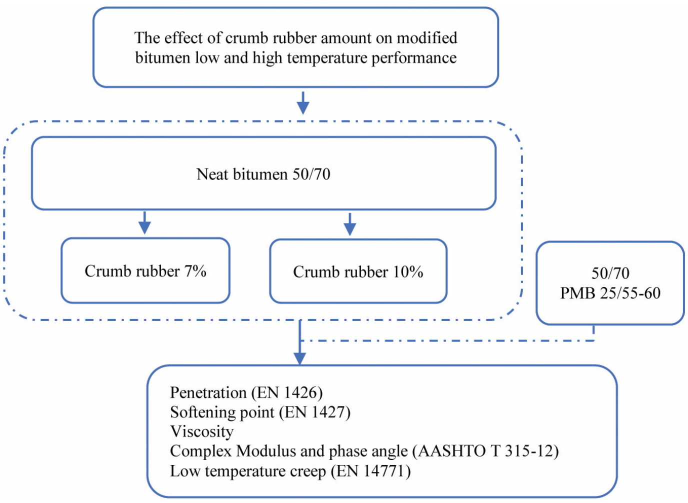

Fig. 1. Flowchart of the experimental research

Results

The effect of crumb rubber content on the modified bitumen penetration is presented in Figure 2. The crumb rubber stiffen bitumen and penetration values decreases from 55.0 mm^{-1} to 31.8 and 32.4 mm^{-1} comparing to the neat bitumen (respectively using 10 and 7% crumb rubber). It was observed a relationship between crumb rubber amount and penetration – penetration decreases with increasing amount of crumb rubber. However, penetration values of neat bitumen with different amount of crumb rubber differ only in 2–3 mm^{-1}, so this difference could be considered as insignificant.

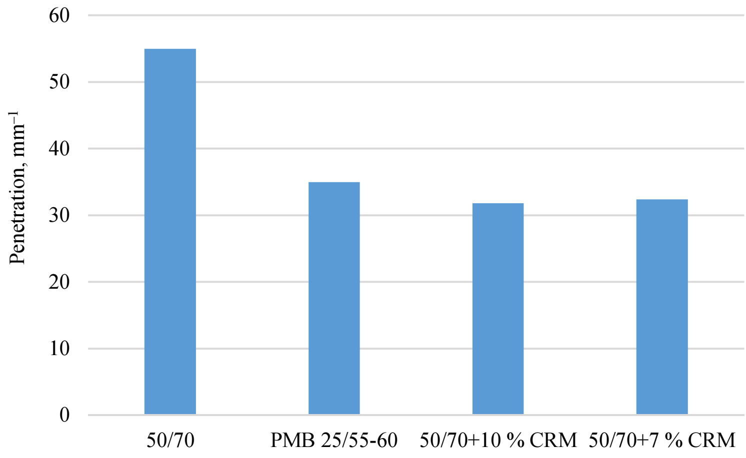

Fig. 2. Results of penetration

Softening point values are given in Figure 3. Modification with crumb rubber increases neat bitumen's softening point from 11.1 to 13.2 °C (respectively using 7 and 10% crumb ruber). A relationship between crumb rubber amount and softening point was determined – the softening point increases with the amount of crumb rubber.

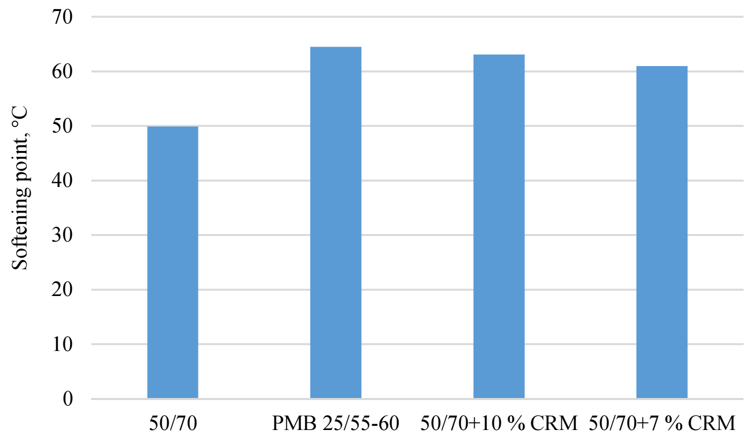

Fig. 3. Results of softening point test

According to penetration and softening point determination results, all crumb rubber modified bitumen are equal to bitumen PMB 25/55-60.

As shown in Figure 4, modified bitumen with 7% of crumb rubber showed better results than bitumen with 10% of crumb rubber in terms of viscosity. Moreover, using 10% of crumb rubber, viscosity exceeds limit of 3000 mPa×s at 135 °C. It could be assumed that 7% of crumb rubber is a threshold in terms of acceptable viscosity. Viscosity should be less than 3000 mPa×s at 135 °C to ensure pump ability at the hot mix asphalt plan. However, practically it is possible to use bitumen, but elevated temperatures should be used in case of highly modified bitumen (Hima).

The effect of crumb rubber and its amount on modified bitumen low temperatures performance is given in Figure 5. Critical temperature increases with increasing crumb rubber content – 7 and 10% of crumb rubber increases critical temperature by 1.05 °C and 3.60 °C, respectively.

The effect of crumb rubber and its amount on modified bitumen high temperatures performance is shown in Figures 6–7. The best performance before RTFOT ageing at all temperatures except 76 °C was obtained by bitumen PMB 25/55-60, while the worst performance was obtained by neat bitumen. Furthermore, it was determined that differences between modified bitumen results at 76 °C were significantly lower than at 58 °C.

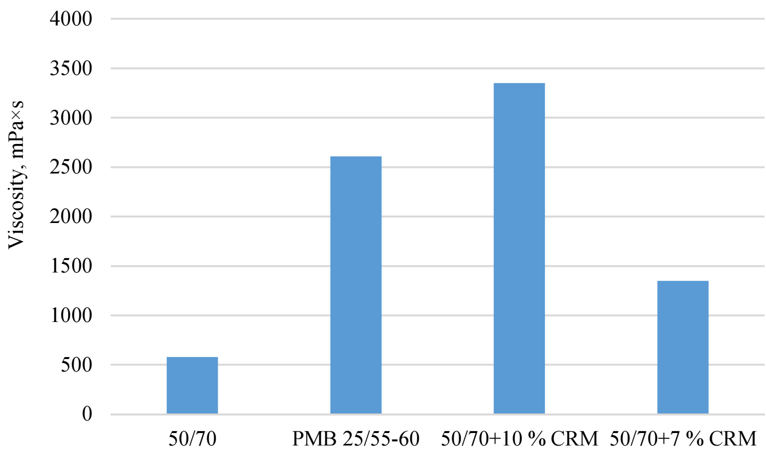

Fig. 4. Results of viscosity test

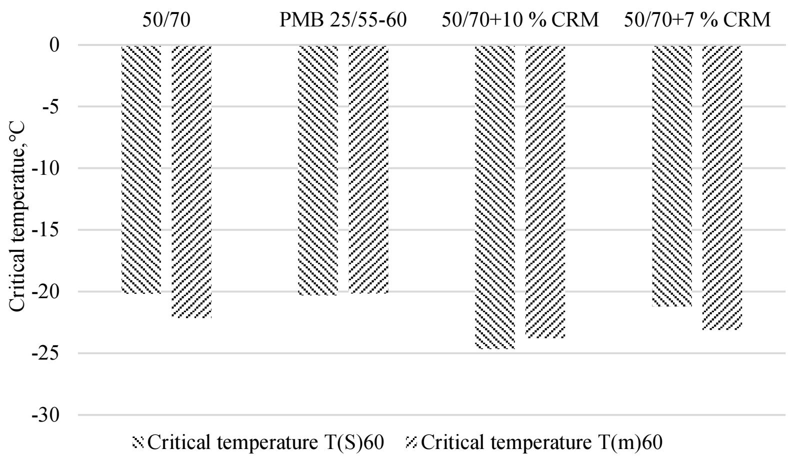

Fig. 5. Results of BBR test

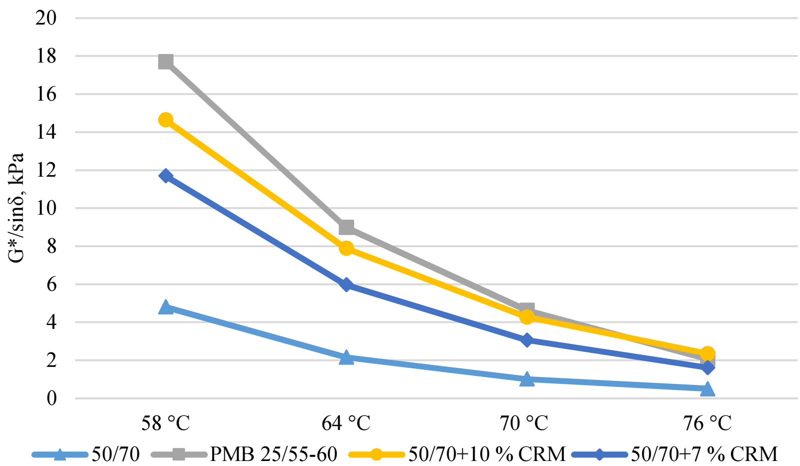

Fig. 6. Results of rutting parameter $G^*/\sin\delta$ at different temperatures before RTFOT ageing

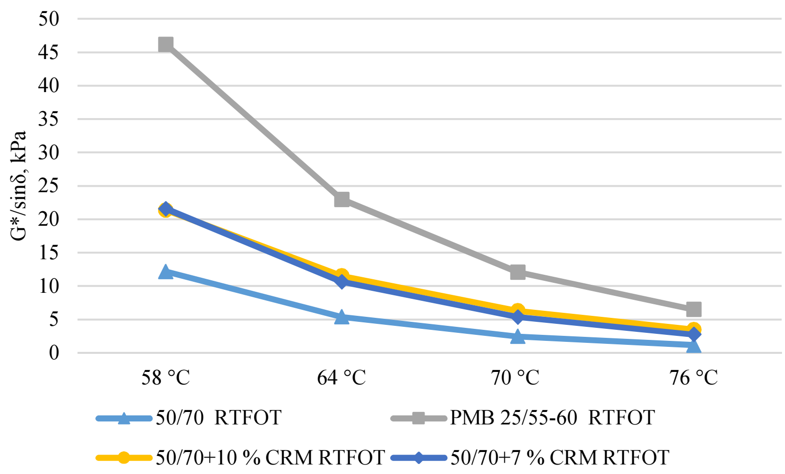

Fig. 7. Results of rutting parameter *G**/sinδ at different temperatures after RTFOT ageing

The effect of crumb rubber and its amount on modified bitumen high temperatures performance after RTFOT ageing are given in Figure 7. The best performance at all temperatures was shown by bitumen PMB 25/55-60, while the worst performance was shown by neat bitumen. It was observed that the differences between results at 76 °C were lower than those obtained at 58 °C. It can be concluded that crumb rubber modified bitumen had a worse performance than PMB 25/55-60 bitumen. The difference between results is increased after RTFOT ageing.

Conclusions

The main findings and conclusions based on performed experimental research were drawn:

According to penetration and softening point determination results, all crumb rubber modified bitumen are within the range of bitumen PMB 25/55-60. Considering obtained results, it is obvious that amount of 7% of crumb rubber is sufficient and usage of higher amounts would be wasteful.

There is observed a noticeable effect on binder viscosity of different amounts of crumb rubber, respectively 7% and 10%: 1350 and 3350 mPa×s at 135 °C. Moreover, with 10% of crumb rubber binder viscosity exceeds limit of 3000 mPa×s at 135 °C.

Critical low temperature increases with the increase of crumb rubber content: 7 and 10% of crumb rubber increase critical temperature by 1.05 °C and 3.60 °C comparing to the neat bitumen, respectively.

All crumb rubber modified bitumen performed better than neat bitumen, but worse than bitumen PMB 25/55-60 in terms of rutting parameter. The difference between results increased after RTFOT ageing.

It is recommended to perform further research on different type bitumen modification with 7% or even lower amount of crumb rubber. According to literature, it could be worth considering to modify neat bitumen with crumb rubber and small amount of polymer. Additionaly, storage stability and elastic recovery of crumb rubber modified bitumen should be evaluated.

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