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THE BEST PRACTISE OF THE OF RECYCLED TYRE RUBBER MODIFIED ASPHALT BINDERS AND MIXES

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Abstract

Rubber derived from grinding of recycled cars and trucks tyres may be successfully used as a binder modifier or supplementary component of the asphalt mix. 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 asphalt binders or asphalt mixes modified with recycled crumb rubber depends on several factors, such as modification method, rubber content and size, modification temperature, mixing speed and time applied during the digestion process. This paper summarizes findings from literature review on the existing technologies and specifications related to the asphalt binders and asphalt mixes modification process with crumb rubber. Moreover, this article summarizes the effect of modified asphalt binder behavior in high and low temperatures. After analysis of the best practise, the algorithm of rubber modified binder and asphalt mix design model was introduced.

Keywords: tyre recycled rubber, modified binder, rubber modified asphalt mix, permanent deformation, fatigue

1 Introduction

The increasing number of vehicles on the roads generates millions of used tyres every year. Used tyres due to the amount and durability are the most problematic sources of waste. Those, same characteristics make waste tyres one of the most re-used waste materials, as rubber is very resilient and can be reused in other products. One of the most successful application is the use waste tyres in road pavements [1]. Asphalt is known as brittle and hard 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 [2]. Scientists suggest failures preventing solutions as the use of high modulus asphalt mixes with polymer modified binder, pavement structure design models with main objectives: field of application, input data (environmental/climate conditions, structural conditions, design materials and loading conditions) and analysis procedure (pavement response to load, pavement response to frost heave and performance (design) criteria). Moreover, there is suggested to apply continuously monitoring of different pavement structures performance and to elaborate on the most suitable and economically effective pavement structures [3-5]. Modification of asphalt binder is a very common practice these days in order to improve its physical properties and performance. Modification of asphalt decreases its temperature susceptibility and this enables asphalt to withstand more load and more severe environments [6]. Incorporation of used tires in asphalt mixtures has been a major advancement in the using recycled materials in asphalt

pavements. Tires contain some of the polymeric components that have been used to modify the asphalt binders for decades, but in a solid form [7]. The use of crumb rubber in asphalt pavements has shown promising beneficial results in previous studies. The aim of this study is to evaluate previous researches and existing specifications on crumb rubber modified binder and asphalt mixtures and provide recommendations based on the best experience.

2 Review of existing modifying technologies and specifications

After the collection of end of life tyres, the next stage of the tyre recycling process is shredding and milling of scrap tyres. Ambient grinding and cryogenic grinding are the most common processes [8]. The use of tyre rubber in bituminous paving materials generally has two distinct approaches: wet process and dry process. Moreover, according to Caltrans [9], the wet process is divided into two families: wet process-high viscosity (asphalt rubber) and high process-no agitation (terminal blend). Detailed description of all this technologies and specifications are given in the following paragraphs.

2.1 Analysis of the dry method

The idea of adding the rubber particles is to substitute a small portion of aggregates with rubber, for the rubber to function just like the aggregates but with additional benefit of possessing elastic properties as illustrated in Figure 1 [10]. The crumb rubber, as a mixture component, at the ambient temperature is added into a blend of heated aggregates prior to introducing binder into the process.

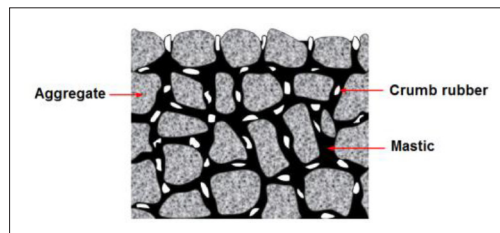


Figure 1 Rubber particles distribution within a gap-graded mixture [10]

Previous studies have specified that in the dry process coarser rubber is used and with this modification, the coarse rubber particles (0.4–10 mm) act as elastic aggregates to increase the mixture's flexibility under loading. Reaction between binder and crumb rubber is considered negligible because the mixtures are fabricated without any significant interaction time between binder and crumb rubber [9, 11, 12]. Higher binder content (1%-2% higher) is needed for the rubberised mixture compared to the conventional mixture for the same aggregate type and gradation [13]. Because of demonstrated variable results, there was a certain lack of confidence in the dry process. However, the most recent researches have recommended to use 0.5-1.5 % of smaller rubber particles (e.g. ≤ 0.6 mm) [14-15]. The dry process can be used in all types of asphalt mixtures. Currently, there is no official guidelines or regulations for dry method modification.

2.2 Analysis of specifications for the wet process-high viscosity method

According to Caltrans [9], the rubber modified binder that maintain or exceed the minimum rotational viscosity threshold of 1.5 Pa·s at 177 °C (or 190 °C) over the interaction period should be described as asphalt rubber binder. These materials require continue agitation,

with special equipment, to keep the rubber particles uniformly distributed. Current Caltrans specifications for asphalt rubber binder call for 20 ± 2 % crumb rubber content by total binder mass [16]. The crumb rubber must include 25 ± 2 % by mass of high natural rubber and 75 ± 2 % scrap tire crumb rubber. The crumb rubber consists primarily of 2 mm to 0.6 mm sized particles. An asphalt modifier, of resinous, high flash point aromatic hydrocarbon compounds (extender oils), is added at a rate of 2.5 to 6.0 % by mass of the asphalt binder. Requirements for the asphalt rubber (after 45 min interacting) are given in the Table 1.

Table 1 Requirements for the asphalt rubber after 45 minutes interacting [16]

Quality characteristic	Test method	Requirement
Cone penetration at 25 °C (mm ⁻¹)	ASTM D217	25–70
Resilience at 25 °C (min, %)	ASTM D5329	18
Softening point (°C)	ASTM D36/36M	52–74
Viscosity at 190 °C (Pa·s) ^a	ASTM D7741/D7741M	1.5–4.0

^aPrepare sample for viscosity test under California Test 388.

During interacting period, the asphalt rubber binder mixture must be stored at 190-218 °C temperature [16]. The asphalt rubber is typically used in gap or open-graded mixes. Asphalt rubber is not best suited for use in dense-graded HMA because there is no enough void space in the dense-graded aggregate matrix to accommodate sufficient asphalt rubber binder content to enhance performance of dense-graded mixes enough to justify the added cost of the binder.

2.3 Analysis of the specifications for the wet process-no-agitation

This is the most recent modifying technology, where crumb rubber is blended with hot binder at the refinery or at a binder storage and distribution terminal and transported to the asphalt plant/job site for use. This technology allows the crumb rubber using as an alternative modifier to polymers, because in this process modifying conditions are similar to polymer modified binder. The crumb rubber is fully digested into the asphalt and polymer without leaving visible, discrete rubber particles [1] (Fig. 2). The terminal blend generally contains 5 % to over 20% crumb rubber, depending on the manufacturer [11]. Polymers and other additives may also be included. In the past, rubber contents for such blends have generally been ≤ 10 % by weight of binder, but some products now include 15% or more crumb rubber [1]. According to Ambaiowei et al. (2014), terminal blends involves 5-12 % crumb rubber particles (≤ 0.6 mm) [17]. The most recent specifications for terminal blends are given in the Caltrans 2015, where modified asphalt binder is defined as asphalt binder modified with polymers, crumb rubber, or both. Requirements for this binder are the same as for polymer modified binders [16]. Considering this facts, viscosity at 135 °C must ≤ 3.0 Pa·s whereas asphalt rubber's viscosity at 190 °C must be 1,5-4,0 Pa·s. Moreover, solubility of the rubber particles must be ≥ 97.5 %. A minimum of 10 % of crumb rubber by mass of binder is required.

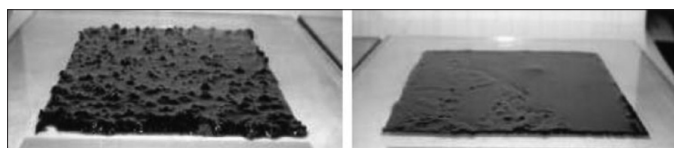


Figure 2 Asphalt rubber (on the left) and terminal blend (on the right) [1]

In the European countries, there is poor literature in this field – only Germany, Poland and Czech Republic have requirements for terminal blends. In Polish standard PN-EN 14023:2011/ Ap1 (2014) is noticed, that binder, modified with crumb rubber, should be marked with sym-

bol CR (e.g. PMB 25/55-60 CR) [18]. That means, that requirements for terminal blends are the same as for polymer modified binder. In German recommendations “Recommendations for rubber-modified binder and asphalts (E GmBA 12), there is given modifying temperature is ≥ 180 °C and the recommended amount of the crumb rubber is 10-20 % (≤ 1.0 mm) crumb rubber [19]. There is no requirements for modified binder viscosity. Asphalt mixtures (SMA, AC, PA) with modified binder (e.g. GmB 25/55-65 and GmBT 25/55-65, respectively wet process and dry process) can be used even for all the highest traffic road pavements. In Czech Republic technical specifications “Technical Recommendation of the Ministry of Transport No 148 Asphalt Rubber pavement courses” for modified binder is given main requirements: crumb rubber amount 5-15 %, viscosity at 150 °C 0.5-1.0 Pa·s and minimum softening point 55 °C, penetration 25-75 mm⁻¹ [20]. Generally, the terminal blends must meet the standard EN 14023 requirements. Terminal blends can be used in all paving and maintenance applications.

3 The effect of asphalt binder and asphalt mixtures modifying on high and low temperatures behaviour

3.1 Dry process

The majority of mechanical testing was undertaken to evaluate mixtures performance in terms of stiffness modulus, permanent deformation and fatigue resistance [13]. Researchers in previous studies have identified the most important variables, which influences performance of the crumb rubber modified asphalt mixtures: rubber gradation and content, aggregate gradation, mixing temperature and curing time prior to compaction (for rubber-binder interactions). The main importance of adding crumb rubber to binder is that the rubber imparts stiffness and elasticity to the binders, which helps increase pavement fatigue life or fatigue resistance, as well as reduces reflective cracking and susceptibility to low-temperature cracking [21]. Kim et al. (2014) have found that fatigue resistances of crumb rubber modified mixtures were significantly improved, compared with the reference mixture without crumb rubber, but the moisture resistance after freeze/thaw treatment was found to be very poor [22]. Dias et al. noticed that crumb rubber modified mixes are less sensitive to high temperatures (above 30 °C) and are more resistant to fatigue than the reference mix [12]. Moreover, crumb rubber modified mixes have shown better resistance to permanent deformations [12, 14]. Chen et al. (2015) pointed out that the use of crumb rubber as mineral filler in an asphalt mixture is helpful in improving the thermal stability of the asphalt mixture, but it slightly reduced the moisture resistance [23].

3.2 Wet process

Considering the facts that wet process-high viscosity process requires additional equipment and it is very complicated technology, this paragraph is focused only on the wet process-no agitation process. A lot of scientists evaluated crumb rubber influence on modified binder behaviour at low and high temperatures and obtained promising results. Ghavibazoo et al. have suggested optimal conditions of modification process: 190 °C temperature, modifying process duration 240 min and speed 50 Hz, 10 % crumb rubber [6]. Another Ghavibazoo et al. (2014) research has indicated that the addition of crumb rubber to asphalt can enhance (decrease) the stiffness of the asphalt at very low temperatures and this enhancement intensifies by increasing the crumb rubber dissolution in binder [24]. Kok and Colak (2011) indicated that to achieve the same performance, as with SBS-modification, the CR-content must be used at much higher than SBS [25]. 8% crumb rubber modification was determined as the most suitable content by determining the permanent and fatigue characteristics and stiffness modulus tests of the control and modified asphalt mixtures. Sybilski et al. (2014) indicated that high modulus asphalt mixtures with crumb rubber modified binder PMB 25/55-60 CR after long

term ageing have shown better resistance to fatigue than mixtures with binder PMB 25/55-60 [26]. Opposite to this, non-aged asphalt mixtures with binder PMB 25/55-60 CR have shown worse resistance to fatigue. Moreover, asphalt mixtures with binder PMB 25/55-60 CR have shown better resistance to low temperatures. The addition of crumb rubber into binder can improve temperature susceptibility, rutting and fatigue characteristics, durability pavements and resistance to oxidative ageing [27]. Poland company “Lotos” noticed that their crumb rubber modified binder PMB 25/55-60 CR and PMB 45/80-55 CR meets with requirements of binder PG 82-22 [28].

4 Rubber modified binder and asphalt mixture design algorithm

From the analysis of existing specifications and scientific researches results, there is drawn a flowchart of rubber modified binder and asphalt mixture design algorithm (Fig. 3).

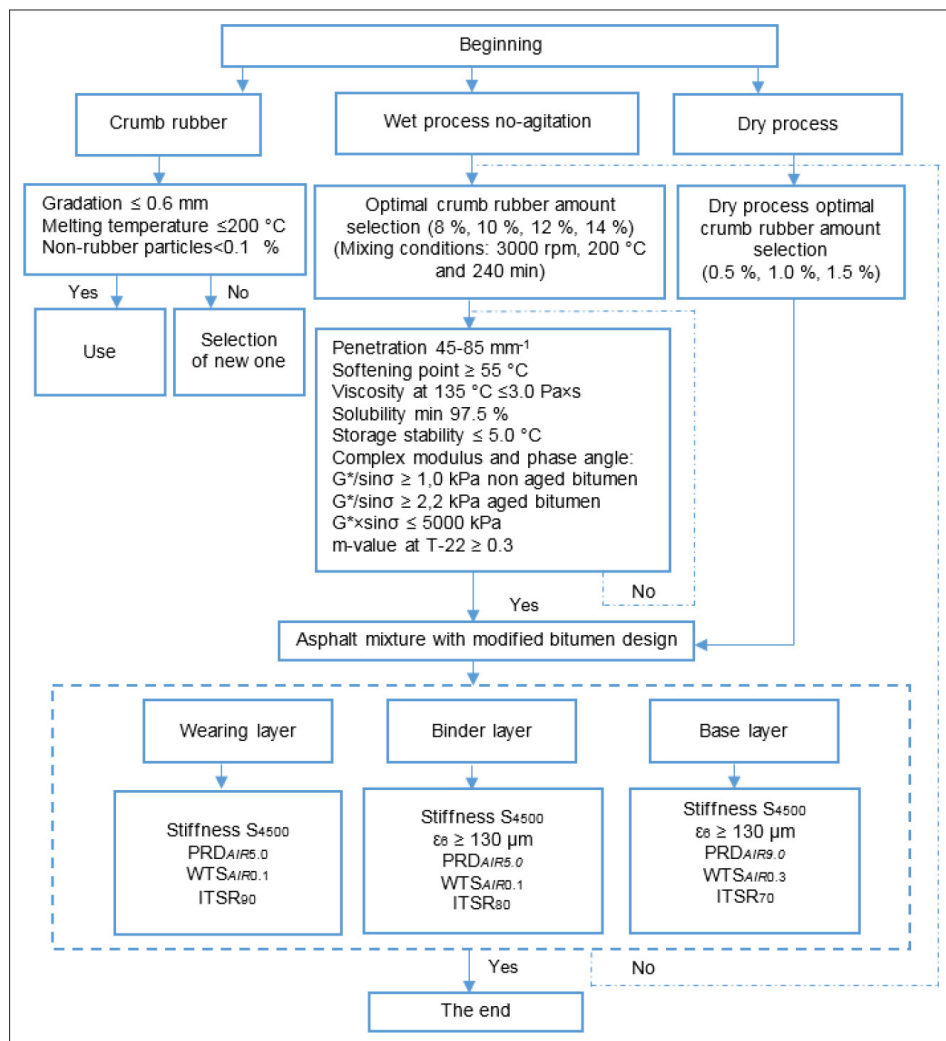


Figure 3 Algorithm of modifying binder and asphalt mixes with crumb rubber

5 Conclusions

The best practise of crumb rubber usage for binder and asphalt mixtures modification has provided better understanding of modifying technologies. Both asphalt modification methods (wet and dry processes) are reasonable for rutting resistance, fatigue and low temperature cracking improvement. The main variables in the dry process are rubber gradation and content, aggregate gradation, mixing temperature and curing time prior to compaction: it is recommended to use 0.5-1.5 % crumb rubber (≤ 0.6 mm) by total mass of mixture for gap and dense graded asphalt mixtures, mixing temperature should be higher 10-20°C than traditional asphalt mixtures. Additionally, it is recommended to apply 60-120 min curing period after mixing.

As wet process-high viscosity is quite sophisticated technology with need of additional installation and asphalt rubber is suitable just for open and gap-graded asphalt mixtures, the widespread use is questionable. As wet process-no agitation technology is very similar to polymer modification technology and asphalt performance results shows very good results it is the most recommended technology for asphalt modification with crumb rubber. Terminal blends can be used in all paving applications and even for the highest traffic road pavements. It is recommended to use that modifying conditions: crumb rubber content 8-14 % by mass of binder, modifying temperature 200 °C and speed 50 Hz.

There is strongly recommended to perform modified binder solubility, viscosity and storage stability tests. Moreover, modified binder and asphalt mixes must be tested before and after long-term ageing procedure. Crumb rubber modified binders must comply with requirements for polymer modified binders and can be classified in the performance graded (PG) system.

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