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Use of modified slow tire pyrolysis product as a rejuvenator for aged bitumen

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HIGHLIGHTS

- Slow pyrolysis of scrap tires was performed.
- Pyrolytic product was successfully used as a rejuvenator for aged bitumen.
- Non-aged and aged bitumen samples were mechanically and rheologically evaluated.
- Interconversion between material functions was completed.
- Pyrolytic product rejuvenated properties of aged bitumen.

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ABSTRACT

Effect of the addition of the pyrolytic product to aged bitumen was studied. Rejuvenator was prepared from scrap tire crumb modified pyrolytic condensate. Polycyclic aromatic hydrocarbons content in the pyrolysis condensate was kept low by applying relative low process temperature; the highest treatment temperature was 500 °C, similarly to those reported in existing studies. 50/70 penetration grade laboratory aged bitumen, prepared by using rolling thin film oven test and accelerated pressure ageing procedure, was used as reference bitumen. The influence of various concentrations of rejuvenator (3%, 5%, 10% and 20%) on the aged and non-aged bitumen was evaluated by standard mechanical and rheological tests. Rheological measurements were performed in the intermediate range by dynamic shear rheometer and in low temperature range with bending beam rheometer. Mechanical functions, dynamic shear modulus $G(\omega)$ and creep compliance $D(t)$, calculated from the rheological test were interconverted to shear $G(t)$ and tensile $E(t)$ relaxation modulus. The results confirmed the suitability of the rejuvenator for modification of the aged bitumen.

1. Introduction

We live in a world of excessive usage of raw materials and increased production of waste. In order to reduce the pollution of used scrap tires, the aim of our study was to evaluate the possibility to use the modified pyrolytic product as a bitumen rejuvenator. The rejuvenator is a bitumen additive, which revives the aged bitumen from reclaimed asphalt. In the present work the pyrolytic products obtained from the slow pyrolysis of scrap tires served as a sustainable basis for the production of the rejuvenator.

Scrap tires represent a dangerous waste as they are non-degradable. Not only do they pose a potential danger to human health (rodents, insects), but can also pollute the environment (uncontrolled emissions of potentially harmful compounds into the atmosphere, soil and groundwater). In recent years, a big progress has been made in the field of recovering scrap tires. Consequently, the percentage of landfilled scrap tires has decreased to 5%, and the percentage of the material recovery increased to 37% in last ten years. In 2012 95% of scrap tires were managed in an environmentally sound and economically viable manner in Europe (EU27, Norway, Switzerland & Turkey). The Landfill Directive [1], which banned the landfilling of the majority of scrap tires, labels the scrap tires as one of the most interesting waste streams in Europe [2]. In 2013 annual tire production increased to 4.7 million tonnes [3], therefore the application of scrap tires as a resource for new products is a way to remove landfilled tires as environmental pollutant. The pavement industry has been using scrap

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tires, which are mainly milled and added to the bitumen as modificators [4].

A pyrolysis is rather old process, like charcoal making from wood. In technical terms, pyrolysis is a thermochemical decomposition of the material at elevated temperatures in the absence of oxygen. The beginnings of tire pyrolysis go back to the late 1920s. However, the pyrolysis of scrap tires received attention not earlier than in the 1990s [5]. Some pyrolytic products of scrap tires have already been investigated [6–8] as fillers to reduce the temperature susceptibility of the bitumen. However, to our knowledge, no study has been reported regarding the application of pyrolytic product as a rejuvenator to the aged bitumen, which is the subject of the present study.

On the European roads the most common surface layer is asphalt, which is due to the environmental conditions and traffic loading subjected to degradation over time. Consequently, a reconstruction of the road is inevitable. The asphalt layer consists of two components: a binder (bitumen) and an aggregate. Both components can be reused. Asphalt recycling presents one of the most important environmental and resource saving possibilities. At first, the reclaimed asphalt (RA) was used only on the low trafficked roads, but nowadays RA can also be used for other infrastructures [9,10]. However, recycling of the asphalt is a complicated process. During its lifetime, the bitumen is aged, and the aggregate is degraded. Furthermore, the process of RA recovery results in the inhomogeneity of the pavement material [11]. The ageing of the bitumen is an ongoing process divided into short-term and long-term ageing process. The bitumen is subjected to short-term ageing during the mixing and asphalt paving procedure; while the long-term ageing lasts throughout the lifetime of the road. Two main mechanisms of ageing could be identified. The more important one is the irreversible process, which includes: oxidation, loss of volatile components and its exudation. The other – reversible mechanism of ageing – is called physical hardening [12,13]. The result of the ageing process is harder and more brittle bitumen, which is one of the most important factors for the deterioration of the asphalt pavements. Special additives, i.e. rejuvenators, help to restore the properties of aged bitumen from RA for further application in new asphalt mixture. The rejuvenators are designed to soften the aged bitumen on the surface of the RA [14] and to assure their complete compatibility. In general, the aged bitumen becomes less viscous, more ductile and its coating properties are restored [15]. The rejuvenators recover the properties of the aged bitumen by reconstructing the chemical composition of the aged bitumen [16]. Different rejuvenators are already in use [16–18]; however, a rejuvenator, prepared from the pyrolysis of scrap tires, has not been reported, yet. In the present work, a rejuvenator was added to the non-aged and aged bitumen at different concentrations in order to test the effect of restoration properties, compatibility and quick mixing properties (fluxing). The purpose of the rejuvenator was to revitalise the aged bitumen from RA. Due to interactions of the rejuvenator with non-aged bitumen, which was added to the asphalt mixture containing RA, the impact of pyrolytic product (designated as PP) on non-aged bitumen was investigated as well.

The aim of this study was to rejuvenate the bitumen from RA, which was previously subjected to short- and long-term ageing. In order to investigate the impact of PP on aged bitumen, the bitumen samples were aged by the rolling thin film oven test (RTFOT) and accelerated pressure ageing (PAV) procedure. The impact of PP addition to the aged and non-aged bitumen was investigated with mechanical testing and rheological properties. The understanding of the rheological behavior of the bitumen is of major concern for asphalt industry, since the mechanical properties of bitumen have a pronounced effect on the in-service behavior of the actual asphalt pavements [19]. When operated and mixed with mineral aggregates at high temperatures, the bitumen is a Newtonian fluid. The resistance of the bitumen to traffic loading (rutting and cracking due to fatigue) is the best described with rheological properties determined in the linear viscoelastic region (LVR). A dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests serve as basic methods to assess the impact of rejuvenator addition on aged bitumen rheology.

2. Materials and test methods

2.1. Pyrolytic product

50/70 penetration grade bitumen (B50/70), from Hungarian manufacturer (MOL), was used as a reference material and as a matrix of the blends.

Pyrolytic product was obtained by the slow pyrolysis of scrap car tires [20] as high temperature condensate, which was afterwards modified by tire crumbs. Selective condensation at 350 °C of hot pyrolysis gases coming from batch (1.5 m^3) pyrolysis at 500 °C (the highest treatment temperature – HTT) provided the basic solid bituminous product. In the second stage of processing, the solid product was totally homogenized at 270–300 °C in a mixer with 25% of scrap tire crumbs (0.5–2 mm). Particle free liquid was vacuumed at 500 mBar to eliminate all light fractions and afterwards the final PP product was obtained (Fig. 1).

The pyrolytic product from tires pyrolysis may contain high concentrations of polycyclic aromatic hydrocarbons (PAH) [5]. Therefore, the slow pyrolysis process of scrap tires was performed at relative low temperature where HTT did not exceed 500 °C. Consequently, a product with low PAH content; i.e. lower than those reported in existing studies [5,21], was obtained.

2.2. Sample preparation

Laboratory prepared blends of 3%, 5%, 10% and 20% PP in non-aged and aged bitumen presented in Table 1 served as basic experimental set. Each of the blended samples weighed 200 g.

The blending process consisted of heating of both components to 130 °C for 60 min, followed by a pouring the required masses into a small container. The two components were then manually stirred together for approximately 5 min to produce a uniformly distributed bitumen blend. The blends were afterwards placed in the sample containers and stored at −18 °C.

2.3. Test methods

2.3.1. Mechanical testing

A two-stage experimental plan consisted of: (i) tests on non-aged bitumen and its blends with PP, and (ii) tests on aged bitumen with various concentrations of PP. Standard mechanical tests and a complete rheological characterization were performed for all samples. Short-term ageing that occurs during the production, transport and application of the asphalt, was simulated by RTFOT. Bitumen samples were aged for 75 min at temperature 163 °C as defined in EN 12607-1 [22]. Long-term ageing to which the bitumen is exposed to through its service life was characterized by PAV procedure, where bitumen sample was aged for 20 h under the pressure of 2.1 MPa at 100 °C (EN 14769 [23]).

Standard testing methods as defined in the European standards were conducted to determine the mechanical properties of bitumen and the blends with PP. In order to determine the consistency of the bitumen needle penetration test according to the EN 1426 [24] at 25 °C was used. The softening properties were determined by using the Ring and Ball method (RB) according to the EN 1427 [25]. Fraass breaking point test according to the EN 12593 [26] was used to determine the brittleness of the bitumen at the low temperatures. The tensile properties of the bitumen were

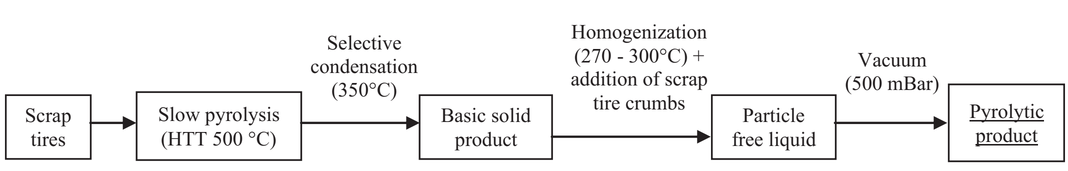

Fig. 1. Graphical presentation of the pyrolysis procedure.