Effectiveness of Different RAP Rejuvenators Obtained from Tests on Marshall Samples

Wojciech Sorociak 1,2, Bartlomiej Grzesik 1
1 Silesian University of Technology, Faculty of Civil Engineering, Akademicka 5, 44-100 Gliwice, Poland
2 Eurovia Polska S.A. Bielany Wrocławskie, ul. Szwedzka 5, 55-040 Kobierzyce, Poland
wojciech.sorociak@polsl.pl

Abstract. Sustainable development is a basic principle of modern world society. One of important aspects of sustainable development is care of natural resources. To achieve this goal it is obligatory to use within building materials those from recycling. In terms of road engineering it refers to all reclaimed materials from pavement construction, however, one of the most valuable of them is reclaimed asphalt pavement (RAP). Its use in production of new hot mix asphalt (HMA) is promoted due to environmental issues but it also causes concerns among road administrators. Aged bitumen, being an ingredient of RAP, poses a threat to new HMA, decreasing its cracking resistance regardless of its source. Aged bitumen is more brittle than the virgin one, thus high RAP content may lead to the same sort of problems within HMA. To enable high RAP content in HMA there are additives (rejuvenators) introduced onto aged bitumen (RAP) to restore its characteristics. Choice between applied rejuvenators is crucial task along with its content in accordance to amount of aged bitumen. The aim of the paper is to pinpoint differences between effects obtained after use of different rejuvenators on mix consisting of 100% RAP. The effect was shown on void content determination and Marshall stability test. Results showed significant differences between 4 rejuvenators of different types, making some of them more effective in comparison to others. Tests confirmed possibility of further investigation on 100% RAP mixes made of confirmed-quality RAP.

1. Introduction
Reycling became an important part of modern world. It is one of the basic actions for whole civilisation to achieve sustainable development. Growing consciousness of the environmental issues is visible in many industry fields, including civil engineering. Within civil engineering it is important to take care of materials obtained from dismantled constructions. In terms of road construction one of the most popular recycling materials is reclaimed asphalt pavement (RAP). The material comes from asphalt layers dismantled from road construction.

RAP is commonly used all over the world. Its highest value it gains when it is used as an ingredient in new Hot Mix Asphalt (HMA). RAP consists of the same ingredients as newly produced HMA. This fact enables RAP to be used in constantly growing content. Due to environmental issues and drive to preserve natural resources it became inevitable to build road pavement containing possibly most recycled materials. Use of RAP is also financially beneficial [12]. As it contains nearly the same amount
of bitumen and aggregate as newly produced HMA it helps to decrease cost of asphalt mix. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

2. RAP use difficulties
There are, however, some issues connected with RAP use. HMA produced with high amount of RAP has high amount of aged binder within its composition. Asphalt binder that underwent ageing processes is more brittle and less flexible than the virgin one. It is also less resistant to low temperatures. Presence of aged bitumen in HMA affects fatigue resistance and frost resistance of asphalt mix [11]. Some researches revealed increased cracking hazard while applying more than 20% of RAP to HMA [1], [3], [4], [5], [6], [8], [10]

The need for utilization of greater than 20% amounts of RAP in HMA is underlined by many specialists [16], [13]. The approach towards the use of high RAP amounts, nevertheless, has to be reasonable. It is crucial to provide i.e. appropriate blending of bitumen, for it may has an impact on HMA characteristics [15], [2]. As the RAP amount reaches much higher level than 30% it becomes advisable to treat the aged bitumen with special agent (rejuvenator), reversing at least part of the changes that occurred within the aged bitumen.

The whole process of bitumen rejuvenation is a subject of many researches [7]. Different rejuvenators’ effectiveness was being tested on asphalt binder. Tests covered both characteristic binder parameters like BBR or DSR, and test of specific rejuvenator influence on binder, like diffusion ability [14]. There were also carried out tests on HMA or even on warm mix asphalt containing RAP with rejuvenator [9]. Despite all the work done, until now it is still not certain if high amounts of RAP containing rejuvenated bitumen in RAP can be safely reused in new road construction layers. Every kind of RAP characterises other parameters and other need for rejuvenation.

3. Research procedure
In this study there was one type of RAP used. Homogeneous RAP was obtained from never renovated, 11 years old road by separately milling asphalt layers. The RAP from base course was stored in closed place protected against changing weather conditions. The origin of the RAP was carefully studied. The studies enabled to determine virgin asphalt binder’s parameters. Afterwards, the basic parameters of RAP and its binder were tested. In table 1 there are compared characteristics of virgin and post ageing RAP binder.

| Property                      | Tested virgin asphalt binder | Tested asphalt binder after 11 years of road exploitation (mean) |
|-------------------------------|------------------------------|-----------------------------------------------------------------|
| Penetration [0,1 mm]          | 45                           | 23 - 27                                                         |
| Softening point [°C]          | 54                           | 60                                                             |

Parameters of RAP are shown in table 2.

| Binder content [%] | Maximum Density [Mg/m3] | Bulk density of asphalt core [Mg/m3] | Air voids content [%] |
|-------------------|--------------------------|------------------------------------|-----------------------|
| 3,5               | 2,642                    | 2,484                              | 6,0                   |
Above described RAP was used as main ingredient of tested HMA mix. Apart from RAP only rejuvenators were used. In the research programme 4 different rejuvenetors were tested. They were named D1-D4. Their basic characteristics were as follows:

- D1 – popular agent based on re-refined industry oils,
- D2 – popular agent – resin of organic origin,
- D3 – soft bitumen of viscosity V6000,
- D4 – experimental agent of animal fat origin.

In the study RAP was used as only ingredient of HMA. To receive asphalt mix it was heated up to 150°C. After reaching the temperature, if planned, the rejuvenator was added and RAP was mixed. The temperature was one again achieved and such mix was used to form Marshall samples by 75 blows per side. All samples had the same heating and mixing time. Prepared Marshall samples were supposed to be tested for air void content (non-destructive test), and stability and flow in Marshall test. All rejuvenators were tested for 4 agent’s content – 0,2%, 0,4%, 0,6% and 0,8% of total RAP mass. As reference were used results obtained from RAP mix without rejuvenator.

4. Results and discussion

Density HMA was acquired every time by taking sample from hot mix right after mixing with rejuvenator. Bulk density of samples was tested with procedure B according to standard EN 12697-6:2012 (saturated surface dry (SSD)). The results are presented in figure 1.

![Figure 1. Air void content of samples containing different amount of tested rejuvenators](image)

Three out of four rejuvenators caused significant drop in air void content after use of rejuvenator. Only additive D3 gave ambiguous results. However, even for D3, when reaching value of 0,6% of rejuvenator content, the drop in air void content was visible. The most efficient rejuvenators decreased air void content by 2% with 0,4% content. Important may be the fact that none of rejuvenators within tested content range, enabled to achieve lower than original (from drilled pavement core) air void content. Nevertheless, rejuvenators made it possible to produce mix, made of RAP, of similar air void content to original.
Stability results from Marshall’s test, according to standard EN 12697-34:2012 are shown in figure 2.

![Figure 2. Marshall’s stability of samples containing different amount of tested rejuvenators](image)

Similarly, to the air void content results, three out of four rejuvenators showed analogical tendency. As the rejuvenator content rises, the stability drops. For D3 the tendency is not obvious. It seems, that soft bitumen enabled to achieve higher results of stability for small quantities while higher quantities did not change significantly stability value.

Flow results from Marshall’s test, according to standard EN 12697-34:2012 are shown in figure 3.

![Figure 3. Marshall’s flow of samples containing different amount of tested rejuvenators](image)
Flow results from Marshall test did not gave clear information. It does not appear to be appropriate test for rejuvenator effectiveness evaluation.

5. Conclusions
Out of three obtained test results the most promising in rejuvenators effectiveness establishment is apparently air void content. The influence of most of rejuvenators on his parameter is repeatable. As the rejuvenators task is restoring virgin binders’ parameters is should decrease viscosity of asphalt binder. It enables to achieve better workability of the mix and to make the HMA similar to original. Thus compacted RAP with cooperating rejuvenator has promising air void content. Loss of stability value is an adverse effect. The use of rejuvenator should be monitored in terms of its content and change of parameters. Effective rejuvenator enables to reach desired parameters (including air void content) still preserving parameters negatively affected by use of agent. Currently it is obligatory to broaden knowledge about the possible effect of rejuvenators and it is necessary to form requirements for effective rejuvenators as it will build trust in sustainable technology of high RAP content mixes.

Acknowledgment(s)
The paper was supported by technical help of Eurovia Polska S.A. The authors are grateful for the support.

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