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Laboratory performance of porous asphalt mixtures containing Ethylene Propylene Diene Monomer - EPDM

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Original scientific paper

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Porous asphalt pavements are environmentally friendly permeable road pavements. There is a need to improve the strength performance of porous asphalt mixtures. Waste Ethylene Propylene Diene Monomer (EPDM) rubber modification of porous asphalt mixtures is investigated in this study. The mixture was initially designed for the selected mix aggregate gradation. Waste EPDM rubber scraps were replaced with filler materials at the rate of 2 % and 4 % of the total aggregate weight. Performance tests were conducted on test specimens. The EPDM rubber scraps improved the elasticity and strength properties of PA mixtures.

Key words:
porous asphalt, ethylene propylene diene monomer (EPDM), recycling, hydraulic conductivity, cantabro particle loss, moisture susceptibility

Izvorni znanstveni rad

Altan Çetin

Svojstva poroznih asfaltnih mješavina s etilen propilen-dienskim monomerom

Porozne asfaltne mješavine upotrebljavaju se za izvedbu ekološki prihvatljivih propusnih habajućih slojeva kolničkih konstrukcija. Dosadašnje iskustvo upotrebe tih mješavina pokazuje da postoji potreba za poboljšanjem njihovih svojstava u pogledu trajnosti. U ovom istraživanju ispitana je modifikacija poroznih asfaltnih mješavina otpadnom etilen propilen-dienskom monomernom (EPDM) gumom. Asfaltna mješavina je prvotno projektirana za odabranu granulometriju agregata. Otpadna EPDM guma se koristila kao zamjena za punilo u udjelu od 2 % i 4 % ukupne mase agregata. Ispitivanje fizikalnih i mehaničkih svojstava provedeno je na ispitnim uzorcima. Dodatkom otpadne EPDM gume poboljšana su svojstva elastičnosti i čvrstoće poroznih asfaltnih mješavina.

Ključne riječi:
porozni asfalt, etilen propilen-dienski monomer-EPDM, recikliranje, propusnost, Cantabro metoda, otpornost na vlagu

1. Introduction

The dissemination of productions and practices aimed at protecting natural resources and reducing environmental pollution is gaining importance on a daily basis. Porous asphalt pavements are environmentally friendly applications, especially in residential areas where they keep rainwater clean, feed underground water sources, and prevent noise pollution [1-4].
These coatings also greatly contribute to driving safety and comfort. They reduce the risk of accidents due to aquaplaning caused by the water film that cannot be drained from the road surface, headlight reflections that may occur during night driving, or low visibility due to water splashes and sprays. In addition, these coats provide a solution to pedestrian inconveniences caused by water splashing in cities [5, 6]. However, research involving appropriate modifications is needed to improve service life of these coating mixtures.
The studies carried out so far are related to the improvement of aggregate properties and gradation, modification of bituminous binder, and reinforcement of mixture with additives. The level of deterioration greatly increases at low temperatures, with the loss of parts in PA mixtures. Binder and mixture modifications are applied to reduce this degradation [7, 8].
The concepts of waste recycling and sustainability appear in all areas of life. Recycling of waste in areas corresponding to their characteristics will provide more economic benefits. Polymer waste, which poses a threat to the environment in terms of waste disposal, has attracted the attention of highway engineers and asphalt coating technologists in recent years. Ethylene propylene diene monomer is one such polymer waste. It has applications in a wide variety of fields, especially in the automotive industry. The world consumption of both natural and synthetic rubbers was 24,845 kt in 2010 [9]. The waste EPDM rubber occurs in various industries, manufacturing units, and automobile repair/service stations. In addition, it is also produced in the form of post-industrial residues from rubber industries involved in the manufacture of roofing membranes, rubber profiles, tire blades, etc. About 1 %-5 % of EPDM production represents residual waste and is usually landfilled [10]. Regular refilling of EPDM is now a costly management challenge for industries that generate/produce this waste. However, this waste can be further explored to consider its use as an asphalt modifier to replace conventional virgin polymers. Its use as an asphalt modifier will also facilitate institutions dealing with its proper disposal and management.
Previous studies have shown that chemically treated EPDM can be used as a viable modifier in asphalt cement and that it exhibits improved stiffness and creep properties in asphalt concrete mixes [11, 12]. It is reported that hot mix asphalts containing EPDM modified bitumen have the potential to improve mechanical strength and moisture sensitivity behaviour [10]. In a study evaluating performance properties of bituminous binders and mixtures modified with waste EPDM, it was determined that the binder improved rutting and fatigue performance. The mixtures demonstrated better stiffness, rutting resistance, and tensile strength, compared to control mixtures [13]. In another study, Ghoreishi et al. [14] studied the combined modification of asphalt binder with EPDM and hybrid nanoparticles (carbon nanotubes and nano-clay). A single EPDM content of 3 % by weight of binder was used in the study. Compared with the control binder, the EPDM-modified binder demonstrated improved physical and rheological properties in terms of higher softening point, lower penetration, higher complex modulus, and lower phase angle.
There is limited information on the effects of waste EPDM rubber on the properties of bituminous binders and mixtures. In general, bituminous binder modification has been studied. It has not been established that the effects of mixture modification by dry method and especially in porous asphalt mixtures have been investigated.
Design parameters of the porous asphalt mixture modified with recycled Ethylene Propylene Diene Monomer were investigated in this study. The optimum bitumen content was determined for the selected aggregate gradation. EPDM additive was added to the mixtures by replacing 2 % and 4 % of the total aggregate weight with filler material. The void analysis was performed on samples prepared with gyratory compactor. The permeability, Cantabro part loss, indirect tensile strength, stiffness modulus, and moisture sensitivity tests were carried out on the samples. The design values of the PA mixtures, and the effects of EPDM on mixture performance, were determined by evaluating the test results.

2. Experimental studies

Turkish Highway Technical Specifications (THTS) were adopted as design criteria In the study in which the effects of EPDM on the performance of PA mixtures were investigated. The experimental research detail is outlined in the flowchart given in Figure 1.

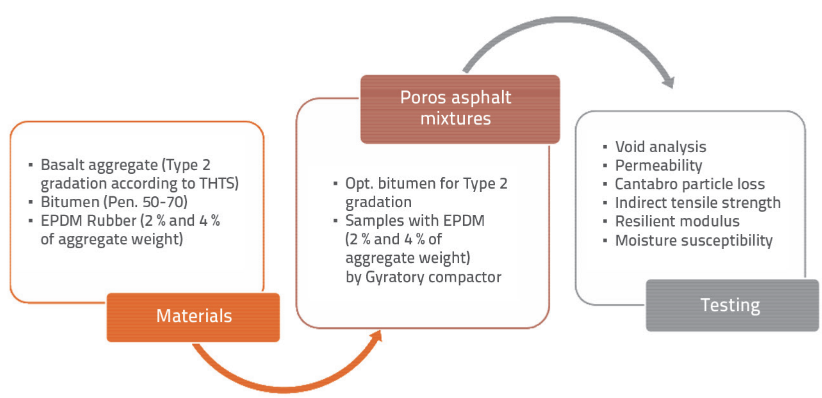

Figure 1. Flowchart of experimental research detail

2.1. Materials

Basalt aggregate obtained from the quarry situated in Eskişehir-Kızılinler-Eşenkara region was used in this study as coarse aggregate, fine aggregate and filler material. Physical properties of basalt aggregate are presented in Table 1. The abrasion resistance of basalt aggregate is quite good. The Type-2 gradation for porous asphalt according to the THTS was chosen as the mixture gradation (Figure 2). Specific gravity and water absorption values determined according to TS EN 1097-6 are shown in Table 2.

Table 1. Physical properties of basalt aggregate

Characteristics	Test method	Values	Limit value
Los Angeles abrasion [%]	TS EN 1097-2	13.5	≥25
Sodium sulphate soundness [%]	TS EN 1367-1	0.64	≥10
Crushing value [%]	TS EN 933-5	100	100
Flakiness index [%]	BS 812	17	<25
Water absorption [%]	TS EN 1097-2	1.59	<2.0

Table 2. Specific gravity and absorption of aggregate

Characteristics	Coarse aggregate	Fine aggregate	Filler
Apparent specific gravity	2.735	2.758	2.774
Bulk specific gravity	2.586	2.637	-
Water absorption [%]	1.59	1.67	-

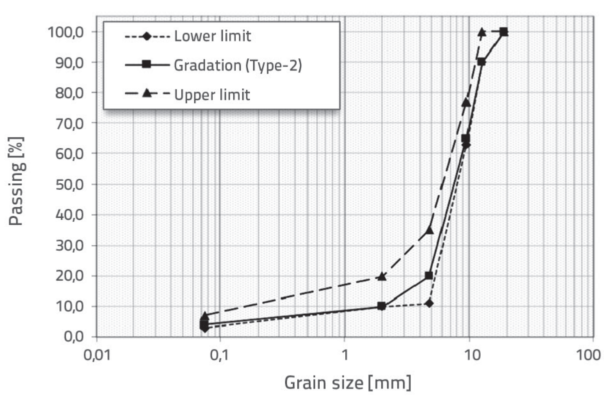

Figure 2. Particle size distribution of basalt aggregate

Since the effect of EPDM modification was discussed in the study, a single type of standard bituminous binder was used. The properties of B 50-70 (penetration class) bitumen, which is manufactured in Kırıkkale Refineries, are shown in Table 3.

Table 3. Bitumen properties

Characteristics	Test method	Values
Penetration, 25 °C. 100 g. 5s (0.1 mm)	TS EN 1426	63
Softening point [°C]	TS EN 1427	48
Flash point [°C]	EN 2592 2592	326
Specific gravity	TS EN 15326	1.011

Recycled EPDM particles shown in Figure 3 were used in mixture modification.

Figure 3. Recycled Ethylene Propylene Diene Monomer (EPDM) rubber scraps

EPDM rubber is a kind of polymer material produced by copolymerization of propylene and unsaturated diene. Ethylene propylene diene rubbers, due to their natural properties as an elastomeric material, provide excellent resistance to outdoor conditions such as heat and oxidation, and to low temperatures environments. Because EPDM is saturated, its resistance to heat, oxygen, ozone and weather conditions is very good [14, 15]. It is a very functional special rubber and is used in automotive parts, rubber hoses and cable production. It participates with approximately 50 % in the rubbers used in automotive rubber products [16]. EPDM has low specific gravity and is suitable for high filler mixtures. The material used in the study was obtained from a company that collects waste tires for use in floor tile production. The part of granular material obtained by grinding waste EPDM rubber materials with No.40 sieve was used. EPDM properties are presented in Table 4.

Table 4. Properties of EPDM Rubber

Characteristics	Values
Tensile strength [MPa]	7- 20
Service temperatures [°C]	-40 ~+150
Coeff. of thermal expansion [μm/mK]	160
Elongation at break [%]	150 ~700
Density [g/cm³]	1.18

This material was replaced with filler material at the rates of 2 % and 4 % of the total aggregate weight. It was mixed dry with aggregate for 2 minutes to reach homogeneous distribution in the mixture.
In addition, 0.3 % of the total mixture weight of bitumen saturated cellulosic fibre was used for stabilizing bitumen in PA mixtures. In order to ensure homogeneous distribution of granular material in the mixture, this material (pellets 7 mm in diameter and 20 mm in length) was mixed dry with the aggregate for 2 minutes before adding the bitumen.

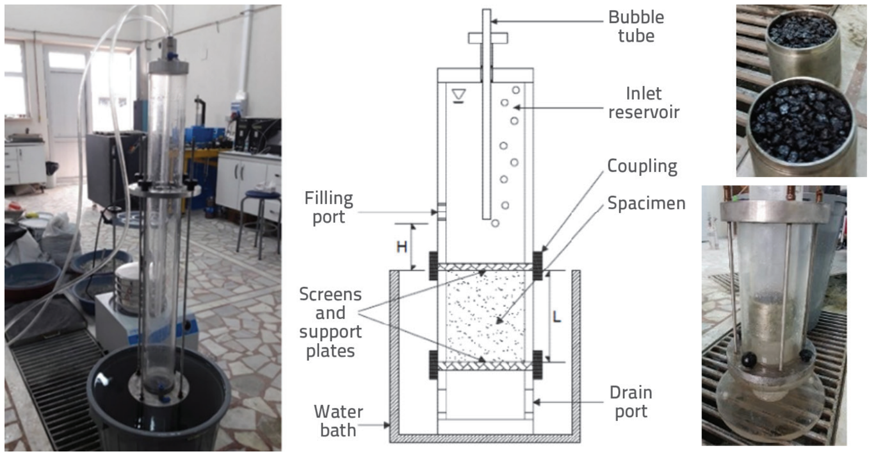

Figure 5. Bubble tube constant head permeability test setup

2.2. Test methods

Optimum design values were determined for the selected permeable asphalt mixture gradation (Type-2), and samples for performance tests were prepared at this optimum bitumen content. In order to ensure homogeneous dispersion of cellulosic fibre and EPDM in the mixtures, the materials were mixed dry with the aggregate for two minutes with a mixer. The bituminous mixtures, which were mixed at 175-180 °C for 2 minutes, were placed in the mould heated at 115-120 °C. Samples were compacted by applying 50 blows on both sides of each sample with Marshall compactor. The samples, which were allowed to cool to room temperature, were removed from the moulds.
Since PA mixtures have high void content, samples must be covered with parafilm to calculate their specific gravity and void ratio (Figure 4).

Figure 4. Compacted samples covered with parafilm

When performing void analysis, it is necessary to determine specific gravity of compacted mix samples (AASHTO T275) and the theoretical specific gravity of the bituminous mix (ASTM D2041).
The permeability test method was used to determine hydraulic conductivity of coarse-grained, high-permeability samples of a certain base area and height. Cylindrical samples 100 mm in diameter were placed in the test system called "constant level permeameter with bubble tube", as shown in Figure 5. This permeameter was placed in a chamber filled with water. The reservoir of the permeameter was filled with water by a vacuum pump. The initial water level (H_s) that stabilizes in the reservoir, and the final level (H_f) at which the water becomes stable after the test, were recorded. The upper water level of the filled chamber was recorded as (H_2), and the water height of the lower level of the bubble tube was recorded as (H_1). The *sample* height *(L),* the time *(t)* needed for water to pass through the sample as the difference between (H_s) and (H_f) levels, and the water flow rate (Q) during this time, were recorded. Darcy's law was used to find the permeability coefficient [17]. According to this law, the permeability coefficient (k) is expressed as follows:

$$k = \frac{(H_s - H_f)}{\frac{(H_2 - H_1)}{L} \cdot t} \tag{1}$$

PA mixtures can form bonds at the coarse aggregate contact points and become more brittle. Therefore, the ravelling and loss of parts occur more frequently in these coatings. The Cantabro particle loss test was developed to determine this situation in the laboratory. The test was carried out according to TS EN 12697-17. A Los Angeles test drum rotating at approximately 33 rpm was used In this experiment. The weight loss of a single sample placed in the drum at the end of 300 cycles was determined. Figure 6 shows a sample before and after the experiment. In this test, the wear loss should exceed 20 %.

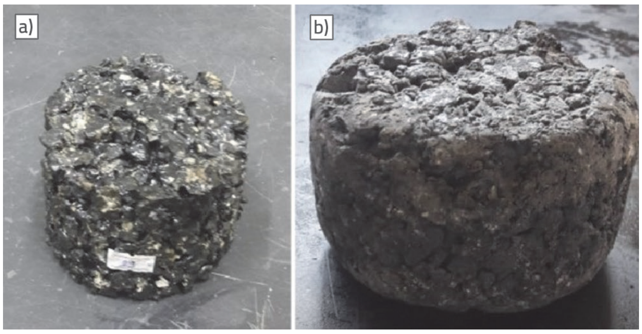

Figure 6. Cantabro particle loss test sample: a) before test; b) after test

Figure 7. Resilient module test system (Asphalt Tester)

The indirect tensile strength test is widely used for the determination of tensile strength, which is important for porous asphalt mixtures. In this method, due to difficulty of applying the direct tensile test, the sample is subjected to an indirect tensile force in the horizontal direction by applying load in the vertical direction. This test, which was carried out in accordance with ASTM D6931, was applied at a deformation rate of 50 mm/min and at a temperature of 25 °C. The tensile stress (s_t) formed perpendicular to the applied load was calculated considering the ultimate fracture load (*P*), sample height (*h*), and sample diameter (*d*).

The modulus of elasticity is widely used to determine the stress-strain and elasticity properties of bituminous mixtures. It is a material parameter used in pavement design and performance estimation. The experiment was conducted using the test system shown in Figure 7. This parameter was determined in accordance with TS EN 12697-26. The experiments were conducted at temperatures of 10 and 20 °C and at a loading frequency of 40 ms.

It is important to determine the strength loss that occurs in bituminous mixtures that are ageing due to climatic conditions and moisture effect. PA mixtures are more significantly affected by the degrading effect of water. The modified Lottman test was applied to the mixtures according to AASHTO T-283 to determine moisture sensitivity. Tensile stresses were determined In this experiment for two sample groups (conditioned and unconditioned). During the conditioning process, a group of samples was kept in the freezer at -18 °C for 16 hours, and then kept in water at 60 °C for 24 hours. Indirect tensile stress values of samples, kept in a water bath at 25 °C for at least 2 hours, were measured. The "indirect tensile ratio" was defined by dividing the indirect tensile stress averages of the conditioned samples by the indirect tensile stress averages of the unconditioned samples. This value gives information about resistance of asphalt mixtures to the effects of water. The indirect tensile ratio should be at least 80 %.

3. Results

3.1. Determination of optimum bitumen content in PA mixtures

Mixture design results for the selected Type-2 gradation are presented in Figure 8. The best results in the Cantabro fragment loss and indirect tensile strength were obtained with 6.5 % of bitumen. It provides limit values of void and permeability values at 6.5 % bitumen content. Therefore, the optimum bitumen content of the PA mixture was determined as 6.5 %. Mixture design results are given in Table 4.

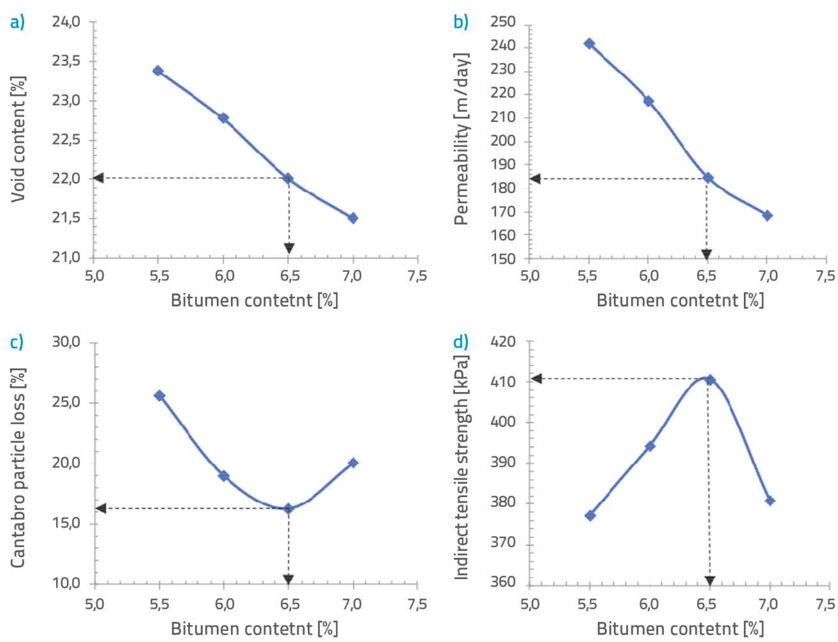

Figure 8. Mixture design results for PA mixtures

3.2. Void and permeability test results

As shown in Figure 9, void ratios of samples decrease as the EPDM replacement increases. This can be attributed to the higher volume of EPDM, which is replaced by weight with filler, due to its specific gravity. Air voids in both replacement ratios provide a minimum limit value of 18 %.

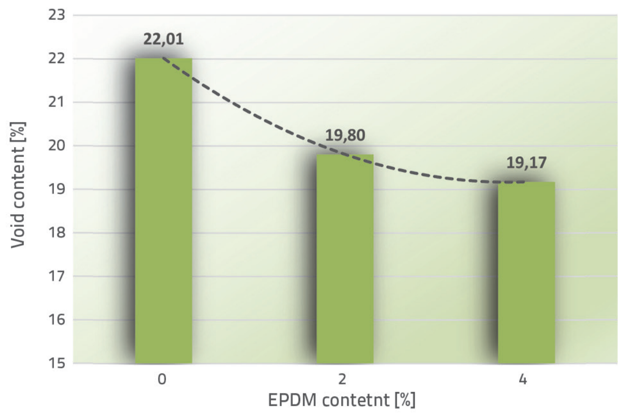

Figure 9. Void contents of PA mixtures at EPDM concentrations

Permeability test results are presented in Figure 10. The permeability coefficient decreased as the EPDM replacement in the mixture increased. It was determined that the permeability constant decreased by 27 % in 2 % EPDM and by 32 % in 4 % EPDM. All results are above the limit value of 100 m/day. Although EPDM replacement reduces permeability, the results are acceptable.

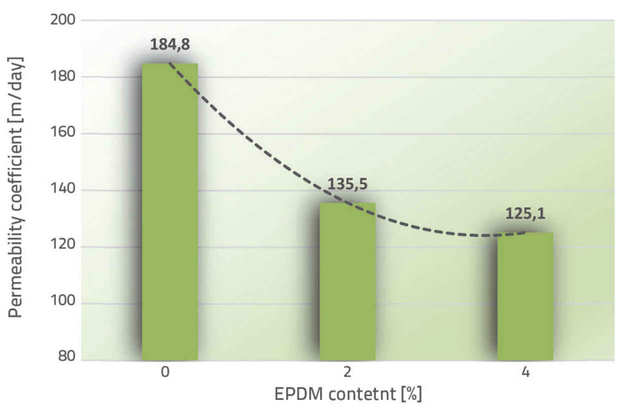

Figure 10. Permeability coefficients of PA mixtures at EPDM concentrations

3.3. Cantabro particle loss test results

As shown in Figure 11, 2 % EPDM replacement resulted in the lowest loss of parts, amounting to 6.1 %. In the case of 4 % EPDM replacement, the loss of parts increased to 11.4 %. It improves those characteristics of lower amount of voids increases. Cantabro part loss. Since mixtures with EPDM have a more elastic structure, the impacts in the experiment were damped. These test results show that all samples are at an acceptable level based on the limit value (20 %) and it would be appropriate to choose the optimum replacement of 2 %.

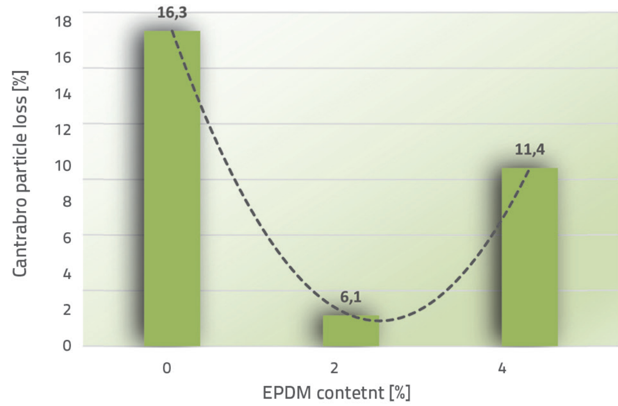

Figure 11. Cantabro particle loss of PA mixtures at EPDM concentrations

3.4. Indirect tensile strength test results

The indirect tensile strength test results are shown in Figure 12. It was determined that indirect tensile strength improved with EPDM replacement, and that the highest result was obtained with 2 % replacement. Indirect tensile strength increased by 13 % in 2 % EPDM and 10 % in 4 % EPDM compared to control samples. These experimental results show that EPDM strengthens the bitumen matrix and supports the results of the Cantabro particle loss test.

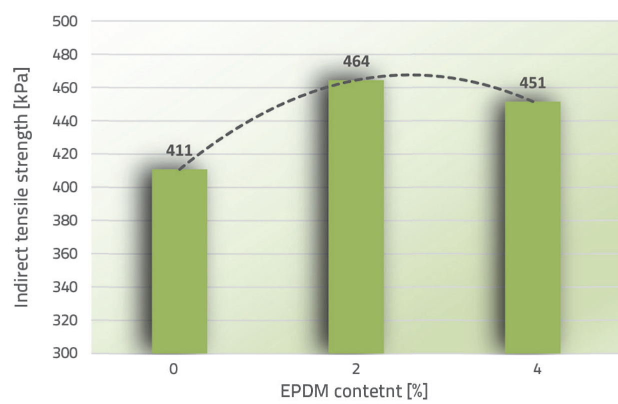

Figure 12. Indirect tensile strength of PA mixtures at EPDM concentrations

3.5. Moisture Susceptibility test results

According to Figure 13, the results for the control and EPDM replacement rates are above 80 % (limit value). EPDM improves sensitivity to moisture. 2 % EPDM increased the TSR by 4.44 %

and 4 % EPDM by 7.7 % compared to the control sample. EPDM rubber improves the cohesion and adhesion of the bitumen matrix against the negative effects of water.

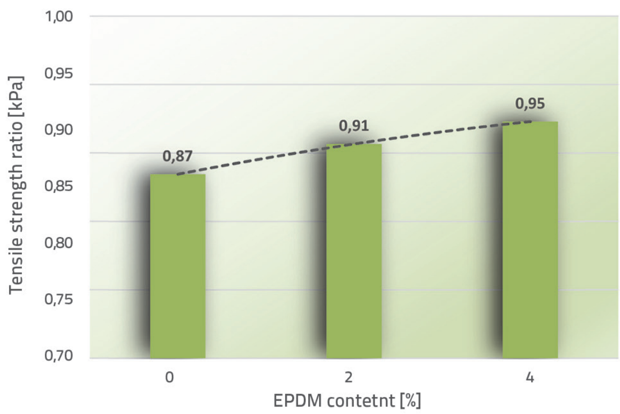

Figure 13. Tensile Strength Ratio (TSR) of PA mixtures at EPDM concentrations

3.6. Resilient modulus test results

The resilient modulus determined by the five-pulse indirect tensile test is shown in Figure 14. Resilient modulus (MR) is a ratio of the applied stress and recoverable strain at a particular temperature and load. Resilient modulus decreases with EPDM replacement at 10 °C and 20 °C. The increasing amount of reversible strain of the mixtures exhibiting more elastic behaviour with EPDM substitution was effective in this respect. This situation is positively reflected in the Cantabro test results. As expected, higher resilient moduli were obtained at 10 °C. Tests at 20 °C showed that resilient moduli were reduced in the control, 2 % EPDM, and 4 % EPDM substitutions by 27 %, 30 %, and 34 %, respectively. Therefore, it is possible to state that EPDM increases the flexibility of mixtures at low temperatures.

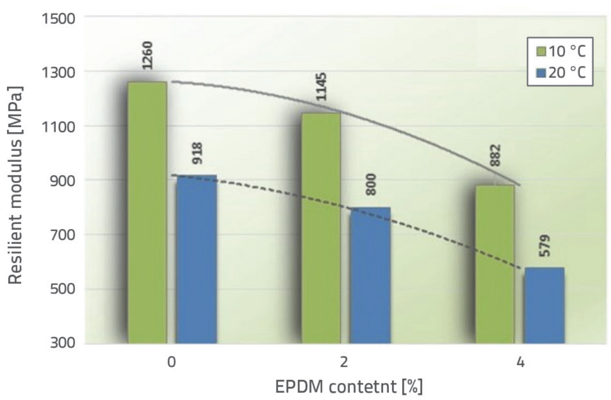

Figure 14. Resilient modulus of PA mixtures at EPDM concentrations

3.7. Optimum mixture design results

An optimum mixture design was determined based on performance test results. The highest tensile strengths were obtained at 2 % EPDM replacement providing the least Cantabro wear value. The air void and permeability results in 2 % EPDM provide limit values. Therefore, it was determined that the optimum mix values were obtained from 2 % EPDM replacement. The results are presented in Table 5.

Table 5. Optimum design results for porous asphalt mixtures

Design parameters	Control	With EPDM	Spec. value
Optimum bitumen [%]	6.5	6.5	-
Opt. EPDM replacement [%]	-	2.0	-
Air void [%]	22.01	19.80	Min. 18
Cantabro particle loss [%]	16.33	6.10	Max. 20
Coefficient of permeability, k [m/day]	184.76	135.54	Min. 100
Ind. tensile strength [kPa]	410.68	464.35	-
Ind. tensile ratio, TSR	0.87	0.91	Min. 80

4. Conclusions

The effects of replacement of waste EPDM rubber particles on porous asphalt mixture performance were investigated in this study. The following conclusions can be made from the performance test results, such as the void ratio, Cantabro particle loss, permeability, indirect tensile strength, and moisture susceptibility:

- Although the air void ratio and permeability of the sample decreased as the EPDM in the mixture increased, the desired limit value was achieved for both replacement ratios. This is due to the larger volume occupied by the EPDM rubber scraps replaced by weight with fillers in the mixture.
- The addition of EPDM improves the Cantabro particle loss of the mixture samples. The best result is obtained at 2 % replacement and the particle loss slightly increased at 4 % EPDM replacement. Although EPDM increased in volume compared to fillers in the mixtures, it improved the stability of the mixtures at the same bitumen ratio. It can therefore be stated that EPDM makes the mixtures more elastic and that it strengthens the bitumen matrix.
- Indirect tensile strength results also demonstrated the positive effect of EPDM on the performance of mixtures. The mixtures exhibited similar behaviour in agreement with the results of the Cantabro particle loss test. The

maximum indirect tensile strength was obtained at 2 % EPDM replacement. This experiment also reveals that EPDM strengthens the bitumen matrix.
- Replacement of EPDM improves moisture sensitivity, and TSR values provide a limit value for replacement rates. These experimental results reveal that the EPDM rubber improves the cohesion and adhesion of the bitumen matrix against negative effects of water.
- The resilient modulus values decrease with EPDM replacement at both temperatures. This is related to the elastic behaviour of EPDM mixtures and the increase in the amount of reversed strain. It can also be stated that EPDM increases the flexibility of mixtures at low temperatures.
- The use of waste EPDM rubber as an additive in porous asphalt mixtures will improve strength characteristics of the mixtures. It will contribute to making porous asphalt mixtures more economical by increasing their service life and expanding their use.
- Positive effects of the dry mixing method for addition of waste EPDM rubber scraps on the performance of the porous asphalt coating mixtures were demonstrated in this study.
- Research on the bitumen modification of EPDM, known as the wet method, can be conducted to improve performance of PA mixtures. The effects of various sizes and concentrations of EPDM on modification can be examined.

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