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PROPERTIES OF ASPHALT CONCRETE WITH BASALT-POLYMER FIBERS

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Asphalt mixtures are commonly used for the pavement construction for national roads with a high traffic load, as well as local roads with low traffic load. The constructions of local road pavement consisting of thinner, more flexible layers located on less stable subbase than the pavement of national roads, require reinforcement with asphalt layers characterized by increased fatigue life. Technologies that allow quick repairs and reinforcements, while improving the durability of the road pavement are being sought. Such technologies include the use of modifications of asphalt mixtures with special fibers. The paper presents the results of investigations of the properties of asphalt mixtures modified with innovative basalt-polymer fibers FRP. On the basis of the obtained test results according to the Marshall method, stiffness modulus and fatigue durability, the technical properties of asphalt mixtures with FRP fibers addition were improved. This technology significantly increases the fatigue life of asphalt concrete dedicated for repairs and reinforcements of road pavements.

Keywords: asphalt concrete, basalt-polymer fibers, stiffness modulus, fatigue life

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1. INTRODUCTION

Over 90% of the road network in Poland are local government roads, including 82.8% poviat and communal roads [1]. They are characterized by low parameters, and their technical condition in comparison to the condition of national roads is definitely worse. Technologies are being sought that allow for quick repairs and reinforcements, and in addition significantly improve the durability of road pavements.

Asphalt mixtures are currently widely used for pavement construction, both on high traffic load national roads and local roads with very low traffic load [2, 3]. These mixtures meet the technical requirements in terms of resistance to traffic load, climatic conditions and widely defined environmental requirements and are part of the concept of road network implementation both on a European scale and in a limited area, e.g. rural areas, for which development it is necessary to use of durable road pavements [4].

Very often, the constructions of local road pavement consist of one or two thin asphalt layers, located on a gravel or sand subgrade. A great number of pavements do not have a top layer bonded with a bituminous binder or cement and they are usually layers of gravel located on deformable weak soil substrates. The most common method of repairing and reinforcement such pavements is to add on the top a new layer of a mineral-asphalt mixture. This layer should be characterized by high technical parameters, including high fatigue durability.

Asphalt concrete is one of the most commonly used mixture for all structural layers of a road pavement. The high quality of asphalt concrete is ensured by using various types of additives that modify the properties of the binder and the asphalt mixture. Currently, the technology of binders and asphalt mixtures with the addition of fibers is becoming more and more significant. A new material and technological solution is the modification of asphalt mixtures with new generation FRP (Fiber Reinforced Polymer) fibers, i.e. basalt-polymer fibers.

The article presents the results of laboratory tests of asphalt concrete, modified with innovative basalt-polymer fibers FRP, with improved technical properties and increased fatigue life.

2. State of art of the use of fibers to modify asphalt mixtures

On the basis of the literature analysis, it should be stated that for the modification of asphalt mixtures with increased durability, the following types of fibers can be used: cellulose, polypropylene, polyester, polyamide, polypropylene aramid, acrylic, glass, steel, mineral (rock) including: carbon, basalt and basalt-polymer FRP. The cellulose fibers most commonly used for asphalt mixtures have a small dispersing (reinforcement) effect of mixtures and are best suited as mastic stabilizers. In the USA, Ohio, the standard requirements for using polypropylene fibers for asphalt mixtures [5] were specified. According to these requirements, the fibers should be homogeneous in terms of dimensions and technical properties and have the following properties: length: 10 ± 2 mm, tensile strength: > 276 MPa, density: 910 ± 4 kg/m^3. Polypropylene fibers should be added to a hot mineral mixture in an amount of approx. 2.7 kg per ton of mixture and mixed for approx. 10 sec. longer than a traditional mineral mixture [6, 7, 8]. The biggest problem associated with the use of polypropylene fibers for hot asphalt mixtures is the low fiber melting temperature, (about 162°C), which was pointed out in [5, 9]. The fibers at this temperature dissolve in the asphalt and may act as a modifier of the asphalt properties but no longer serve as fibers reinforcing the asphalt mixture [9].

Research conducted at the University of Arizona of asphalt mixtures with the addition of polypropylene aramid fibers showed an increase of 25 to 50% of the strength of intermediate tensile mixtures and increased fatigue life [7, 8, 10].

The addition of carbon fibers to asphalt mixtures improves the resistance to permanent deformation of these mixtures. According to [5, 8] when using 0.1 to 0.5% carbon fibers with a length of 1.0 to 1.5 of the maximum grain size of the aggregate, increases the Marshall stability of the asphalt mixture, decreases strain (flow) of samples modified against samples without the addition of fibers.

An interesting technological solution is the simultaneous application of cellulose, polyester and basalt fibers to asphalt mixtures [7, 11]. According to research conducted at the Wuhan University of Technology in China such mixtures are characterized by increased resistance to rutting and increased fatigue durability. It was also shown that the addition of fibers extends the temperature range of the viscoelastic properties of the asphalt mixture [7, 11].

The use of basalt fibers is the most common method for modifying asphalt mixtures in hot and cold technology. The addition of basalt fibers to asphalt mixtures according to tests [5, 11] contributes to the increase of stiffness of mixtures at high operating temperatures and does not cause excessive stiffening at low temperatures.

The use of FRP fibers in the form of carbon-polymer fibers CFRP, glass-polymer GFRP, basalt-polymer BFRP, aramid-polymer AFRP and hybrid G/C FRP for modification of bituminous mixtures is recognized to a much lesser extent.

In the literature, there are no studies on asphalt mixtures with the addition of a new generation of basalt-polymer fibers FRP. On the basis of research carried out at Warsaw University of Technology [7] it was found that the use of dispersed reinforcement in the form of FRP fibers gives good results in the case of asphalt mixtures with continuous graining curve.

3. MATERIALS AND TEST METHODOLOGY

In the laboratory tests, asphalt concrete mixture AC 11 S for wearing course was used as the reference mixture for FRP fibers modification and as a comparative mixture. The following materials were used to prepare samples of AC 11 S: limestone filler, basalt sand fraction 0/2 mm, basalt fraction 2/5 mm, 4/8 mm and 8/11 mm and bitumen 50/70 from the Polish refinery. In order to modify the asphalt mixture, FRP basalt-polymer fibers with a length of approximately 12 mm were used (Figure 1).

The properties of the basalt-polymer fibers used are shown in Table 1.

Fig. 1. Basalt-polymer fibers with a length of 12 mm

Table 1. Requirements of basalt-polymer FRP fibers

Properties	Values
Technological temperature range, °C	-260 do 680
Melting temperature, °C	1450
Density, Mg/m^3	2800
Fiber diameter, μm	13-20
Fiber length, mm	ok. 12
Tensile strength, MPa	4840
Young's modulus, GPa	89
Elongation at break, %	3.15

The AC 11 S asphalt mixture was designed in accordance with the WT-2 Technical Requirements [12], selecting the mineral mixture using the best grain grading control points.

In the Table 2 the composition of the designed asphalt mixture AC 11 S, designed for further modification with different FRP fibers content, is presented.

Table 2. Asphalt mixture composition of AC 11 S

Materials	Mineral mixture composition, % (m/m)	Asphalt mixture composition, % (m/m)
Limestone filler < 0.063 mm	6.3	6.0
Crushed sand 0/2 mm	33.7	32.0
Basalt aggregate 2/5 mm	14.0	13.3
Basalt aggregate 4/8 mm	21.0	19.9
Basalt aggregate 8/11 mm	25.0	23.7
Road bitumen 50/70	-	5.1

Bitumen content was adopted according to WT-2 using the method of the minimum allowable B_{min} content. The content of binder in the asphalt mixture determined was B = 5.1%.

In the production process of the asphalt mixture, fibers, regardless of their origin, are traditionally added to the hot aggregate and after thorough mixing, a hot binder is added. As proven by the authors previous experience, the fibers introduced into the aggregate tend to form agglomerates, and they are difficult to evenly distribute in the mineral mixture. This phenomenon occurs both in laboratory production and in the mixing plant of mineral-asphalt mixtures. The Warsaw University of Technology has developed a fiber addition technology, i.e. staged dosing, with simultaneous mixing, which facilitated the homogenisation of the fiber-modified mixture. Modification with fibers, due to the low content of the additive, does not require adjusting the temperature of production of the asphalt mixture.

The second important issue is the length of fibers. It is assumed that the appropriate length of the fiber used as the asphalt mixture modifier should be in the range from 1 to 1.5 times the largest aggregate grain of the mineral mixture. Fibers shorter than nominal have not a beneficial effect on the properties of the mixture. Too long fibers will prevent the production of a homogeneous asphalt mixture. Due to the selection of an asphalt concrete mixture of 11 mm grain for testing, it was assumed that the length of FRP fibers should be 12 ± 1 mm. Four levels of modification of the asphalt mixture with FRP fibers were adopted, i.e. 0.1%, 0.3%, 0.5% and 0.7% in relation to the weight of the asphalt mixture.

The research program for the FRP fiber-modified mineral-asphalt mixtures covered the following properties: air void content, mechanical properties according to Marshall method, i.e. stability, flow and Marshall stiffness index, stiffness modulus and fatigue life by the 4-point bending of the beam.

In order to calculate the air void content in compacted samples of FRP modified asphalt mixture and the reference mixture, density tests were carried out according to PN-EN 12697-5 (by pycnometric method) and bulk density according to PN-EN 12697-6. The samples of asphalt mixtures were subjected to Marshall tests according to PN-EN 12697-34. The result of the test is stability, i.e. maximum resistance to settling of the sample from the asphalt mixture (maximum force at the moment of sample destruction) and flow, i.e. deformation of the sample at the time of its destruction. The ratio of stability to flow allows the calculation of the Marshall stiffness index, which is a preliminary assessment of the mechanical properties of the asphalt mixture. The test was carried out at 60°C.

For the assessment of both rheological properties of bituminous binders and properties of asphalt mixtures with these binders, the examination of the stiffness modulus of the mixture is described, eg described in papers [13, 14, 15], which can be assessed by various methods according to PN-EN 12697-26. The stiffness of asphalt concrete with the addition of FRP fibers was evaluated in a four-point bending test on a prismatic sample (4PB-PR). The tests of the stiffness and fatigue life using the 4-point beam bending method were performed on 55 × 55 × 400 mm prismatic samples cut from slabs in accordance with the compaction direction. Testing of fatigue life of bituminous mixtures with different FRP fiber content was performed in the DTS-30 device in accordance with the PN-EN 12697-24 standard at 10°C at a strain frequency of 10 Hz. Stiffness modules were determined for the 100th load cycle with strain amplitude $\varepsilon = 50$ μm/m. The fatigue life of the sample was determined when its stiffness modulus reached 50% in relation to the initial value determined in the hundredth cycle of the test.

4. TESTS RESULTS AND ANALYSIS

Analyzing the results of research on volumetric parameters of asphalt concrete with various fiber content, it can be concluded that the addition of FRP fibers does not significantly affect the volumetric density and air voids in the samples. The addition of FRP fibers, with the assumed contents and length of fibers, does not affect the deterioration of the compactability of asphalt mixtures. The results of tests of mechanical properties of asphalt mixtures according to the Marshall method are presented in Fig. 2 (Marshall stability) and in Fig. 3 (Marshall stiffness index).

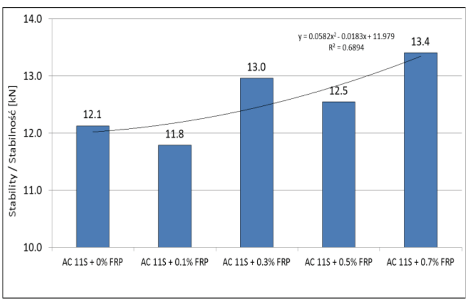

Fig. 2. Marshall stability of compacted samples of asphalt mixtures with FRP

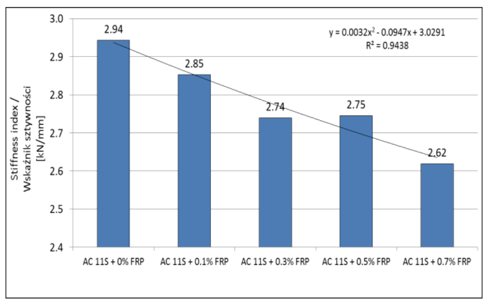

Fig. 3. Marshall stiffness index of compacted samples of asphalt mixtures with FRP

Based on the test results of the stability of asphalt mixtures, it can be concluded that the addition of FRP fibers results in a slight increase in the stability of the samples. This phenomenon is particularly visible when the fiber content is 0.3%, while the addition of 0.1% fibers does not improve this property. It can be concluded that for the sake of stability the best solution is to apply 0.3% fibers to asphalt concrete.

As shown in Fig. 3, the addition of FRP fibers reduces the Marshall stiffness index. It follows that as the content of fiber addition increases, the stability of the asphalt mixture increases and the flow (deformation) of the samples increases. It is assumed that the stiffness index should be in the range of 2 to 6 kN/mm for asphalt mixtures. Mixtures with an index above 6 kN/mm may have low resistance to fatigue and low resistance to temperature cracking. In mixtures with an index below 2 kN/mm may occur viscoplastic permanent deformation [16]. In the case of asphalt mixes with the addition of FRP fibers, it can be stated that this phenomenon will result in an improvement in the fatigue life of mixtures with the increase of the fiber addition content. Taking into account the stability study and assessment of the stiffness index, it should be concluded that the content of 0.3% fiber additive is the most favorable solution.

In Fig. 4 and Fig.5 the results of stiffness and fatigue life tests in the four-point bending test of samples from the AC 11S asphalt mixture with different FRP fiber content were presented.

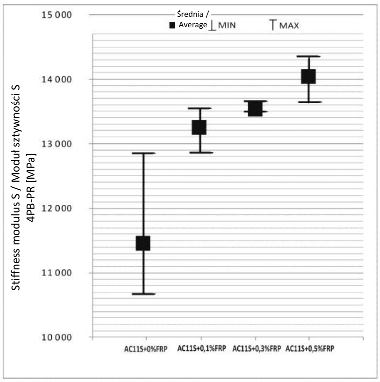

Fig. 4. Stiffness modulus 4PB-PR of AC 11S asphalt concrete with FRP

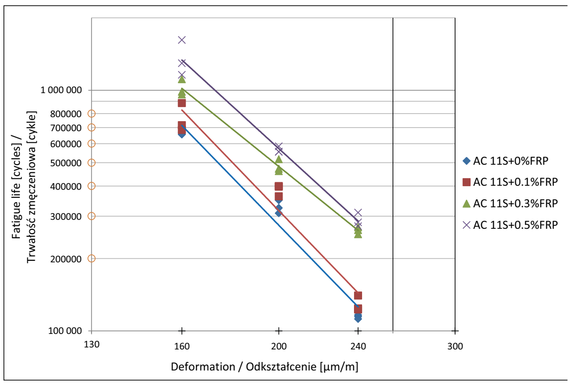

Fig. 5. Fatigue life of AC 11S asphalt concrete with FRP

Based on the results of the tests presented in Fig. 4, it should be noted that the addition of FRP fibers causes a significant increase in the stiffness modulus of asphalt mixtures. The increase in the stiffness of asphalt mixture with FRP fibers in relation to the asphalt mixture without fibers indicates the strengthening properties of this type of modification, which may result in an increase in the resistance of the modified asphalt mixture to permanent deformation. Increasing the fiber content in the asphalt mixture results in an increase in the stiffness modulus, but this increase is not as large as the increase in stiffness using a fiber content of 0.1% compared to the reference sample without added fibers.

The test results of fatigue life of asphalt concrete mixtures with the addition of FRP fibers were described by regression equations, determining the functional relations between deformation and fatigue life for specific contents of the FRP fibers additive (Table 3).

Table 3. Regression models of fatigue life of AC 11S asphalt mixtures with FRP

Asphalt mixture type and fiber amount	Regression model	R^2
AC 11S + 0%FRP	$N_f = 1.940E+15 \cdot \varepsilon_f^{-4,280}$	0.97
AC 11S + 0.1%FRP	$N_f = 2.702E+15 \cdot \varepsilon_f^{-4,316}$	0.95

AC 11S + 0.3%FRP	$N_f = 2.462E+13 \cdot \varepsilon_f^{-3,350}$	0.99
AC 11S + 0.5%FRP	$N_f = 3.176E+14 \cdot \varepsilon_f^{-3,800}$	0.98

The equations presented in Tab. 4 were used to determine fatigue life for asphalt mixtures with different FRP fiber content and at different levels of deformation values. Based on the results of the tests presented in Fig. 5, it should be noted that the addition of FRP fibers to asphalt concretes significantly improves the fatigue life of the analyzed asphalt mixtures. With an average strain level of 200 μm/m for the FRP fiber additive of 0.1%, an increase in fatigue life of asphalt mixtures is about 18% compare to the reference mixture (no fibers added), for an additive 0.3% FRP fibers - about 48% and for the additive 0.5% FRP fibers - about 73%. It can be assumed that with the content of fibers in the asphalt mixture equal to 0.3% there is a high, very beneficial increase in fatigue life, which in the reinforced road pavement will ensure longer life of the pavement construction. Thanks to this, the repaired pavement will be able to be successfully exploit, providing road users with high comfort and safety.

5. CONCLUSIONS

In order to improve the technical properties, especially the fatigue resistance of asphalt mixtures, various modifications, including fiber additions, are used. At Warsaw University of Technology, work is under way to determine the effect of modifying asphalt mixtures with new generation additives in the form of basalt-polymer fibers FRP. Based on the obtained results, it can be concluded that the addition of FRP fibers to asphalt concrete results in an increase in Marshall stability and a decrease in the Marshall stiffness index, which may result in improved resistance of bituminous mixtures to cracks. The increase in the stiffness of asphalt concrete with FRP fibers in compare to the mixture without fibers was confirmed in the stiffness test using a 4-point bending test of the beam, which indicates the strengthening properties of this type of modification, leading to an increase in the resistance of the mixture to permanent deformation.

Based on the results of fatigue life tests, it should be stated that the addition of FRP fibers to asphalt concretes significantly improves their fatigue durability, and if 0.3% of the fibers are used, the increase in durability exceeds 50%.

ACKNOWLEDGEMENTS

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WŁAŚCIWOŚCI BETONU ASFALTOWEGO Z DODATKIEM WŁÓKIEN BAZALTOWO-POLIMEROWYCH

P. RADZISZEWSKI , M. SARNOWSKI , A. PLEWA P. POKORSKI

Słowa kluczowe: beton asfaltowy, włókna bazaltowo-polimerowe, moduł sztywności, trwałość zmęczeniowa

STRESZCZENIE:

Mieszanki mineralno-asfaltowe powszechnie stosuje się do budowy nawierzchni, zarówno dróg krajowych o dużym obciążeniu, jak i dróg lokalnych o małym obciążeniu. Konstrukcje nawierzchni dróg lokalnych składające się z cieńszych bardziej podatnych warstw położonych na mniej stabilnych podłożach niż nawierzchnie dróg krajowych wymagają wzmocnienia warstwami asfaltowymi charakteryzującymi się zwiększoną trwałością zmęczeniową. Do takich technologii zaliczyć można beton asfaltowy modyfikowany specjalnymi, innowacyjnymi włóknami bazaltowo-polimerowymi FRP. W pracy przedstawiono wyniki badań właściwości betonu asfaltowego AC 11S z asfaltem 50/70 oraz z dodatkiem włókien bazaltowo-polimerowych FRP o właściwościach przedstawionych w Tabl. 1.

Tablica 1. Właściwości włókien polimerowo-bazaltowych FRP

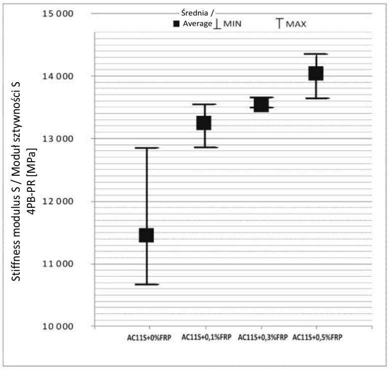
Właściwość	Wartość
Zakres temperatur technologicznych, °C	-260 do 680
Temperatura topienia, °C	1450
Gęstość, Mg/m^3	2800
Średnica włókna, µm	13-20
Długość włókna, mm	ok. 12
Wytrzymałość na rozciąganie, MPa	4840
Moduł Younga, GPa	89
Wydłużenie przy zerwaniu, %	3.15

Przyjęto 4 poziomy modyfikacji mieszanki mineralno-asfaltowej włóknami FRP, tj. 0.1%, 0.3%, 0.5% i 0.7% w stosunku do masy mieszanki mineralno-asfaltowej.

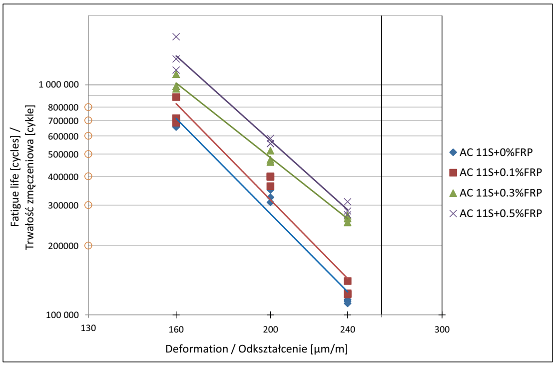
Program badań mieszanek mineralno-asfaltowych modyfikowanych włóknami FRP obejmował następujące oznaczenia: zawartości wolnych przestrzeni, właściwości mechanicznych wg Marshalla, tj. stabilności, osiadania, wskaźnika sztywności, modułu sztywności i trwałości zmęczeniowej metodą cztero-punktowego zginania belki.

Analizując wyniki badań dotyczące parametrów objętościowych betonu asfaltowego z różną zawartością włókien można stwierdzić, że dodatek włókien FRP nie wpływa w znaczący sposób na zmianę gęstości objętościowej oraz zawartość wolnej przestrzeni w próbkach. Wyniki badań stabilności mieszanek mineralno-asfaltowych wykazały, że dodatek włókien FRP powoduje wzrost stabilności próbek. Zjawisko to widoczne jest szczególnie przy zawartości włókien 0.3%. Odwrotna zależność występuje przy ocenie wskaźnika sztywności wg Marshalla. Dodatek włókien FRP powoduje zmniejszenie wskaźnika sztywności wg Marshalla i na podstawie tego można prognozować, że zjawisko to będzie skutkowało poprawą trwałości zmęczeniowej mieszanek wraz ze wzrostem zawartości dodatku włókien. Mając na uwadze badanie stabilności i ocenę wskaźnika sztywności należy wnioskować, że zawartość dodatku włókien 0.3% jest

rozwiązaniem najbardziej korzystnym. Wyniki oznaczeń modułów sztywności oraz trwałości zmęczeniowej w badaniu cztero-punktowego zginania próbek z mieszanki mineralno-asfaltowej AC 11S z różną zawartością włókien FRP przedstawiono odpowiednio na Rys. 1 i na Rys. 2.



Rys. 1. Wartości modułów sztywności 4PB-PR betonu asfaltowego AC 11S z dodatkiem włókien FRP



Rys. 2. Trwałość zmęczeniowa betonu asfaltowego AC 11S z dodatkiem włókien FRP

Na podstawie wyników badań przedstawionych na Rys. 1 należy stwierdzić, że dodatek włókien FRP powoduje znaczący wzrost modułu sztywności mieszanek mineralno-asfaltowych. Wzrost sztywności mieszanek z włóknami FRP w stosunku do mieszanki bez włókien wskazuje na wzmacniający charakter tego rodzaju modyfikacji, co może skutkować zwiększeniem odporności mieszanki modyfikowanej na odkształcenia trwałe. Z Rys. 2 wynika, że dodatek włókien FRP do betonów asfaltowych znacznie poprawia trwałość zmęczeniową mieszanek mineralno-asfaltowych. Przy średnim poziomie odkształcenia 200 μm/m dla dodatku włókien FRP o zawartości 0.1%, otrzymano wzrost trwałości zmęczeniowej mieszanek mineralno-asfaltowych o około 18% w odniesieniu do mieszanki referencyjnej (bez dodatku włókien), dla dodatku 0.3% włókien FRP - o około 48% i dla dodatku 0.5% włókien FRP – o około 73%.

Podsumowując uzyskane wyniki badań, można stwierdzić, że dodatek włókien FRP do betonu asfaltowego powoduje wzrost odporności mieszanki na odkształcenia trwałe oraz znaczącą poprawę trwałości zmęczeniowej, co spowoduje wydłużenie czasu eksploatacji remontowanej i wzmacnianej nawierzchni drogowej. Dzięki temu ta nawierzchnia będzie mogła być dalej z powodzeniem eksploatowana zapewniając użytkownikom drogi odpowiednio wysoki komfort jazdy i bezpieczeństwo.