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Influence of bitumen type on cracking resistance of asphalt mixtures used in pavement overlays

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Abstract. Cracking is one of the predominant distresses occurring in flexible pavements, especially in old pavements that were rehabilitated with an asphalt overlay. In such cases asphalt mixtures should be designed to ensure high resistance to reflective cracking because new asphalt layers are exposed to existing cracks of the old pavement. The nature of these cracks can be various (transverse, longitudinal as well as crazy cracking). One factor that minimizes this type of distress is the proper mix design process, which should involve selection of specific bitumen binder and mineral mix gradation. However, still there is no universally adopted laboratory test method that would allow to clearly assess resistance of asphalt mixtures to reflective cracking. This paper describes the usage of one of the devices developed to test asphalt mixtures in terms of such distress – Texas Overlay Tester. For this test, samples prepared in laboratory conditions (i.e. compacted with the use of Superpave Gyratory Compactor) as well as obtained in the field (by core drilling) can be used. The results are obtained not only quickly and easily, but also with sufficient repeatability. The described method characterizes both crack initiation and crack propagation properties of asphalt mixtures. In this work one type of mineral mixture was tested with 4 different types of bitumen (one neat bitumen, two ordinary polymer-modified and one polymer-modified with high polymer content). For selected cases extra additives (rubber and loose fibres) were also tested. In total, six asphalt mixtures were tested. A ranking of the used binders was created on the basis of the results in order to conclude which bitumen would ensure the best performance characteristics in terms of reflective cracking. The results have clearly shown that deliberate choice of the binder used in the asphalt mixture for the overlay will significantly improve its reflective cracking resistance or even fatigue resistance.

1. Introduction

The risk of cracking is one of the most important issues that can affect pavement condition and performance during its operation life. This problem is often considered as significant mainly for old pavements (especially rigid ones, with concrete wearing courses) that are due to be rehabilitated by placing new asphalt overlay, but undesirable cracking can also occur in relatively new pavements that contain stiff, rigid base courses, e.g. aggregates or soils bound with hydraulic binders. It should be emphasised that the issue of cracking susceptibility of asphalt mixtures also influences the fundamental pavement characteristics, such as fatigue life and ageing-related performance. Even new pavements, which otherwise would be structurally sound and long lasting, when constructed with asphalt mixtures that are stiff and highly susceptible to cracking will show premature distress, often much earlier than anticipated.

There are several approaches to mitigating the problem of pavement cracking. In situations when there is a risk that cracks from the existing old pavement or hydraulically bound base course will reflect in the new asphalt layers placed over the top, the following techniques are often considered and used: (1) reinforcing of asphalt layers with geosynthetics of different nature (geogrids, geonets, geocomposites, glass grids, fabrics) or metal mesh, (2) introducing stress relief layers (SAMI, chip sealing, very open asphalt mixture), (3) controlling of reflective cracking by sawing the asphalt overlay [28]. More radical technologies, but used only when concrete pavement is rehabilitated, involve elimination of movements in the concrete layers by fracturing concrete slabs into smaller fragments or rubblizing them into coarse aggregate fraction.

Another approach to increasing general pavement resistance to cracking is to enhance anti-cracking characteristics of the asphalt mixture. This can be achieved by various means: by selecting a certain type of the binder and its amount, type and gradation size of the aggregate mixture and also by incorporating different additives into the binder or asphalt mixture as a whole, e.g. polymers, recycled rubber, fibres or natural bitumen [3, 10, 11, 15, 17, 27].

Obtaining asphalt mixture that would possess higher resistance to cracking depends not only on the mix design process alone, but must also incorporate proper test method [27], allowing to differentiate asphalt mixtures in terms of cracking characteristics. For many years efforts were mainly put into development of test methods concerning resistance to permanent deformation (Wheel Tracking Test, Hamburg Wheel Tracking Test, Asphalt Pavement Analyzer), fatigue life (4-point bending test, 2-point bending test) or low-temperature properties (TSRST, ATCA). Development of test methods dedicated specifically for cracking characteristics was initiated only in recent years, when it transpired that the current asphalt mixtures, which are optimized for good rutting performance and have a high RAP content, can be more prone to cracking than the mixtures used previously. Nowadays, there are several methods of measuring asphalt mixture cracking susceptibility: (1) Semi Circular Bending test at different temperatures (SCB), (2) Disc Shape Compact Tension test (DCT), (3) Bending Beam Fatigue (BBF), (4) Indirect Tensile test (IDT) and (5) Texas Overlay Tester (TxOT). Each of the mentioned methods has its own specific characteristics and advantages, while none of them is widely adopted. Nevertheless, taking into consideration their different specific criteria of assessing cracking resistance of asphalt mixtures, TxOT method seems to be quite promising.

The first version of the Texas Overlay Tester was developed by Germann and Lytton [9]. The method at that stage used rectangular prismatic beams and modelled horizontal displacements resulting from thermal stresses that occur in overlaid old pavements. It was developed to assess resistance of asphalt mixtures to reflective cracking that can occur in new layers placed on existing pavements. The influence of fabric was also investigated. In later years the method was modified by Zhou and Scullion [24] to accommodate other shapes of specimens, so that it would be possible to prepare them more easily in the laboratory or core them in the field. At the moment, overlay tester is routinely used by Texas DOT which has developed its own testing procedure Tex248-F [19, 20], but a similar international standard ASTM WK26816 [2] does also exist. In Poland there are still no publications or research reports available concerning the use of the TxOT in Polish conditions (Polish types of mixtures, common bitumens etc.).

2. Objectives and scope of the research

The objective of the research was to verify the feasibility of the TxOT method in assessing cracking characteristics of the asphalt mixture prepared with binders routinely used in Poland, especially in terms of different bitumen types and special additives incorporated in the mixture composition.

The scope of the research included testing of one type of asphalt mixture with different bitumens and selected additives. The asphalt mixture chosen for the research was specifically prepared for overlay applications (such as levelling course placed on old concrete asphalt pavement before placing final wearing course) and was based on typical asphalt mixture AC 11W for traditional binder course. Four different bitumens included one neat bitumen, two polymer-modified bitumens (soft and hard) and one highly polymer-modified bitumen. All tested bitumens are normally used in Poland in asphalt mixtures for binder course. In case of the mixture with neat bitumen two different additives were also used: crumb rubber and polymer fibres.

3. Tested materials

3.1. Bitumens

Four different bitumens were selected for this study: neat bitumen 35/50, two polymer SBS-modified bitumens: 10/40-65, 25/55-60 and highly SBS-modified bitumen 25/55-80. All bitumens were produced in a Polish refinery. Properties and performance grade (PG) of bitumens (acc. to AASHTO M320 [1]) used in this research are shown in Table 1.

Table 1. Properties of bitumens.

Property		Type of bitumen				
		35/50	**35/50 R**	**10/40-65**	**25/55-60**	**25/55-80**
Penetration at 25°C, 0.1 mm, acc. to PN-EN 1426	Original	45	39	26	34	50
	RTFOT	28	24	21	25	41
R&B Temperature, °C, acc. to PN-EN 1427	Original	53.0	60.7	68.0	62.6	87.5
	RTFOT	60.1	69.9	71.4	68.2	89.1
Performance Grade, acc. to AASHTO M 320		70-16	82-16	82-16	76-22	82-22

R – rubber modification

3.2. Asphalt mixture

Asphalt concrete used in this study was designed according to EN 13108-1 standard [6] and Polish Technical Guidelines WT-2 2014 [14]. The composition and volumetric properties of basic mixture AC 11 W with 35/50 bitumen compacted by Marshall hammer are presented in Table 2. For other bitumens the same aggregate composition and binder content (set to 5.6%) was used and only the type of bitumen was changed.

Table 2. Composition and volumetric properties of basic asphalt mixture AC 11 W 35/50.

Type of layer	binder/levelling course
Type of traffic	medium, design life from 0.50×10^6 to 7.3×10^6 of 100 kN standard axle loads
Aggregate type	crushed granite
Filler type	limestone
Binder content (% by mass)	5.6
Air voids in Marshall samples (2 x 75 blows) [%]	3.3
Voids filled with bitumen VFB [%]	80.4
Voids in the mineral aggregate VMA [%]	16.6

Sieve size (mm)	16	11.2	8	5.6	4	2	0.125	0.063
% Passing (by mass)	100	99	83	65	54	43	12	7.4

Asphalt mixtures were prepared with the use of laboratory mixer in accordance with EN 12697-35 standard [5]. Before compaction, loose portion of each asphalt mixture was aged in accordance with the procedure given in the Appendix 2 of the WT-2:2014 [14] to simulate short-term aging of bitumen during production, transport and paving of asphalt mixture.

3.2.1. Additives to asphalt mixture

For asphalt mixture with neat 35/50 bitumen, two different methods of asphalt mixture modification were also tested: addition of polymer fibres and rubber modification.

The first method consisted of adding 19 mm long polymer aramid-polyalphaolefin fibres directly to asphalt mixture. The fibres that were used are specially designed for use as reinforcement in asphalt mixtures for pavement structures. Fibres were added during mixing process with a dosage rate of 0.05% by weight of asphalt mixture. The addition of fibres improves asphalt mixture performance properties [3, 11, 12].

The second method consisted of adding recycled tyre rubber. This was achieved in the laboratory by mixing the proportion of 191 grams of ground tyre rubber (0.2/0.8mm), 9 grams of a specific polymer (polyoctynamer) and 2000 grams of asphalt binder. The mixing process was performed by using laboratory mixer with 200 RPM and 120 minutes of mixing time. The temperature during mixing process was held between of 170 – 180°C. The process of mixing described above is used for the specific additive only during laboratory phase because during full scale production it is added directly to the mixing chamber of the asphalt plant and mixed with dry aggregate for 8-10 seconds, before liquid bitumen is added. Any kind of rubber modification improves asphalt mixture properties, especially in the field of low-temperature cracking [4, 13, 15, 16, 18, 23].

3.2.2. Basic properties of asphalt mixtures

To obtain basic information about the influence of binder and additives on asphalt mixture properties, wheel tracking test acc. to EN 12697-22 was conducted. The results of this test are shown in table 3.

Table 3. Wheel tracking test results.

Binder type	35/50	35/50 R	35/50 F	10/40-65	25/55-60	25/55-80
Rutting resistance, method B in air, 60°C, 10 000 cycles						
WTS_{AIR}, [mm/1000 cycles]	0.28	0.09	0.25	0.19	0.15	0.12
PRD_{AIR}, [%]	6.7	3.3	6.2	5.3	4.5	3.8

R – rubber modification, F – fibre modification

4. Test methodology

The methodology of the test that was used in this study was similar to Texas Standard Procedure Tex-248-F [20].

4.1. Sample preparation (compaction, trimming, mounting in the test device)

The overlay test specimen consists of a 150 mm long, 75 mm wide and 37.5 mm thick sample that is trimmed from a typical gyratory compacted sample with a diameter of 150 mm and height of 115 mm. Gyratory samples were compacted in accordance with EN 12697-31 standard [4], to obtain target density of 98-100% of Marshall density in the further trimmed test specimens. Trimmed specimen dimensions are shown in Fig. 1. Table 4 shows air voids content in trimmed test samples for each asphalt mixture. For each asphalt mixture three specimens were prepared and tested.

The compaction temperature for asphalt mixtures prepared with neat bitumen 35/50 was 135°C ± 5°C, whereas for asphalt mixtures with polymer-modified bitumens it was 145°C ± 5°C.

Table 4. Air voids in final trimmed test specimens.

Binder type	35/50	35/50 R	35/50 F	10/40-65	25/55-60	25/55-80
Air voids content [%]	5.3	5.4	5.2	5.3	5.2	5.1

R – rubber modification, F – fibre modification

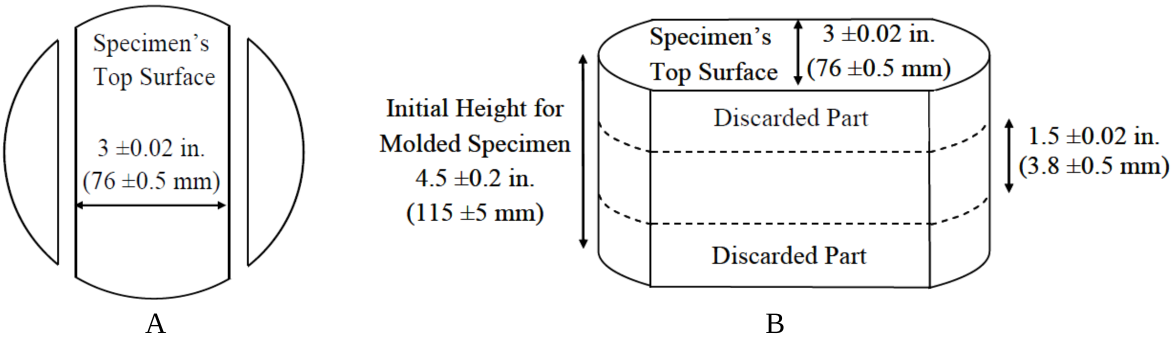

Figure 1. Test specimen dimension according to Tex-248-F standard [20].

Once prepared, each sample was glued with epoxy glue on two metalllic plates, which were securely fixed to a wide mounting plate, as shown in Fig. 2.

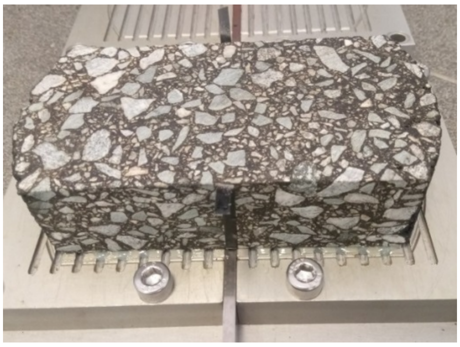

Figure 2. Trimmed specimen glued to the mounting plates.

4.2. Load mode and measurements

Once dried, the samples glued to the plates were mounted in the UTM 130 Texas Overlay Tester jig (see Fig. 3) making the setup ready for the test. The test was conducted in a controlled displacement mode, at a loading rate of one cycle per 10 seconds with a maximum displacement of 0.63 mm, at temperature +25 ± 0.5°C. Each cycle consisted of 5 seconds of loading and 5 seconds of unloading (see Fig. 4). The test was conducted until the failure of the specimen occurred.

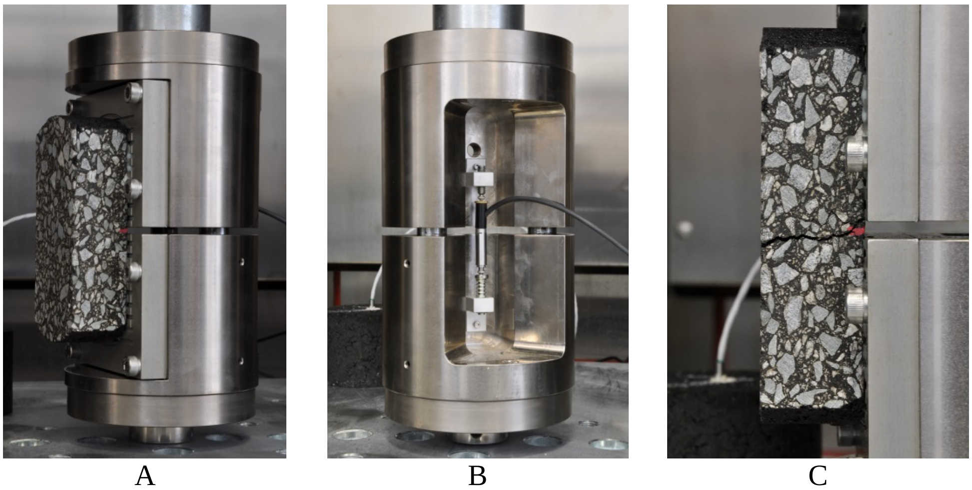

Figure 3. A – specimen mounted in the UTM 130 Overlay test jig, B – external LVDT transducer, C – cracked samples at the end of the test.

The number of cycles to failure was defined as the number of cycles to reach a 93% drop in initial load which is measured during the opening cycle. If a 93% reduction in initial load was not reached within a certain specified maximum number of cycles, the test was stopped automatically. Initially, a total number of 1,000 loading cycles was selected as a maximum number of cycles for stopping the test; however, later it was increased to 2,000 cycles, since no failures were observed after 1,000 loading cycles for the evaluated overlay mixtures, especially with highly modified polymer bitumen. At the end of the test, initial and final values of load, percent reduction in load and number of cycles to failure were reported.

Typical plot of load and displacement during the test is shown in Figure 4. As it can be seen, during the first stage of load cycle (first 5 seconds of cycle) sample is subjected to tension load, while during the second stage (from 5 to 10 seconds of cycle) sample is subjected to compression. Load needed to obtain a constant deformation amplitude is changing during the test. At the first cycle tension load is higher than compression load needed to set sample deformation to zero position, while during the rest of the test the compressive force begins to exceed the tensile force. Compression during cycles can be considered as a form of material's healing.

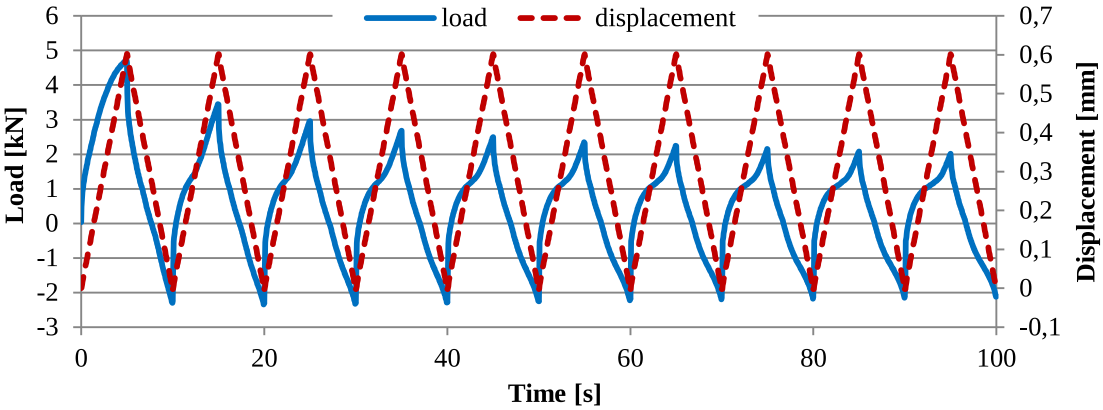

Figure 4. Typical plot of load and displacement during the test (first 10 cycles).

4.3. Cracking resistance criteria

4.3.1. The maximum number of cycles to failure

Based on the current TxOT failure criterion, asphalt mixtures that last over 300 load cycles to failure, defined as load reduction of 93% in the initial load, are judged as acceptable in terms of resistance to cracking [25]. The mixture that reach over 750 load cycles to failure can be treated as an anti-cracking layer [8, 21]. In the latest version of TxOT standard [20] the maximum number of cycles to failure is treated only as an informational value.

4.3.2. The critical fracture energy

The idea of critical fracture energy computation is shown in Figure 5. Critical fracture energy is represented by the area under the load vs. displacement chart (from zero to maximum value) during the first cycle of loading [20].

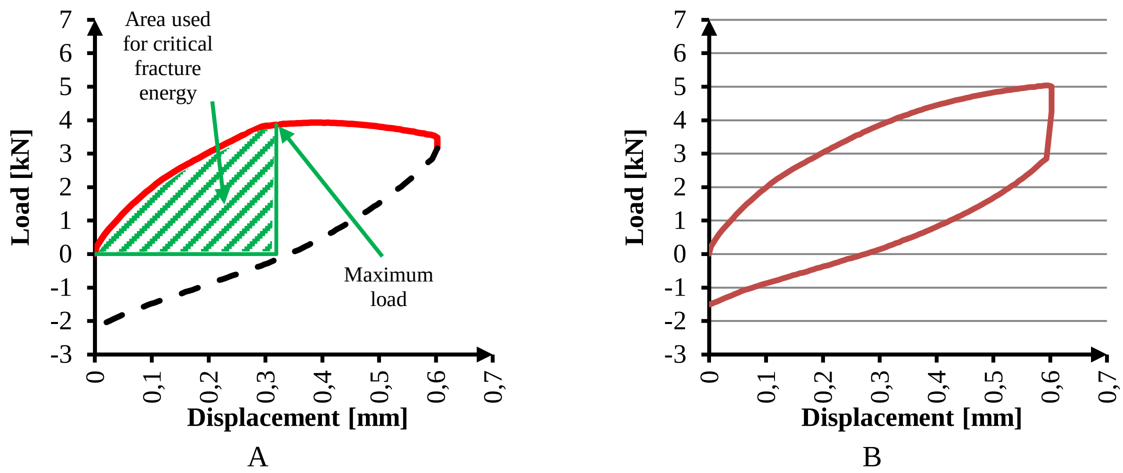

Figure 5. Graphical representation of the critical fracture energy of the first cycle, A – the idea of the method, B – shape of hysteresis loop achieved for tested mixtures.

4.3.3. Crack propagation (Crack Resistance Index, Crack Progression Rate)

Crack propagation stage of asphalt mixture behaviour can be described by Crack Resistance Index [20] or by Crack Progression Rate [8], both calculated from load reduction curve by fitting a power equation. This idea is shown in Figure 6.

According to Garcia et al. [8], the cracking resistance of asphalt mixtures can be subjectively divided into four categories: I) Tough-Crack Resistant: good resistance during crack initiation (tough) and propagation (flexible). Asphalt mixtures with acceptable cracking resistance should be in this quadrant; II) Tough-Crack Susceptible: asphalt mixtures with good resistance to crack initiation (tough) but susceptible to crack propagation (brittle); III) Soft-Crack Resistant: easy crack initiation (soft) but good abilities to attenuate the propagation of the crack (flexible); IV) Soft-Crack Susceptible: asphalt mixtures with significantly poor resistance to crack initiation and propagation. This idea, along with the obtained test results, is shown in Figure 8.

5. Results and analysis

Figure 6 shows crack driving force during loading cycles for all tested mixtures. Fig. 7 presents hysteresis loops from the first loading cycles. Overlay test results are summarized in Table 5.

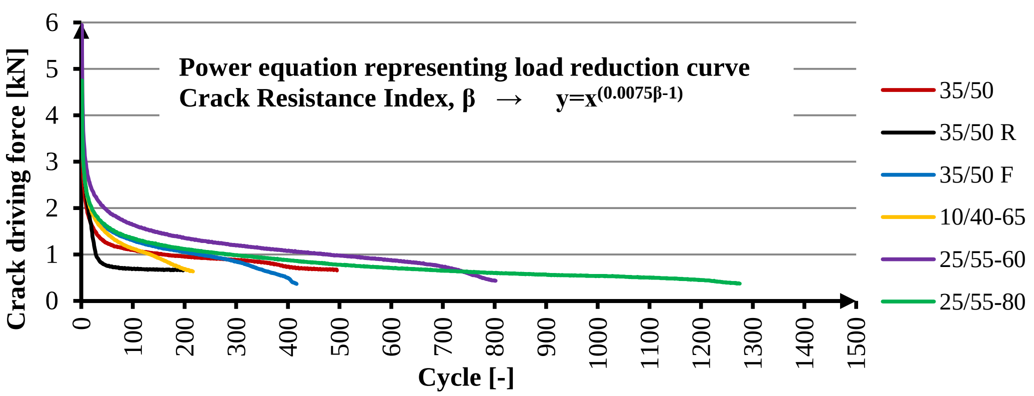

Figure 6. Crack driving force diagram, one line for each asphalt mix (first specimen from the series, not a mean value).

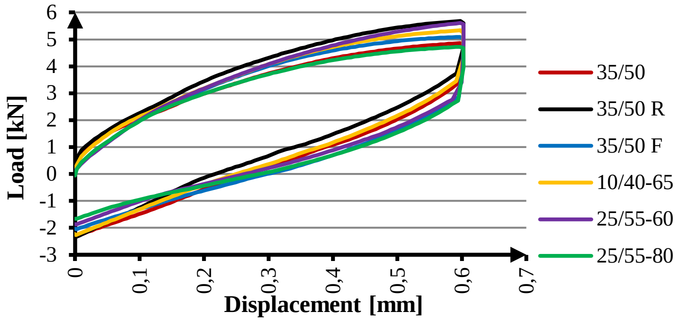

Figure 7. Hysteresis loops from the first load cycles, mean values for three specimens.

Table 5. Summary of TxOT results, mean values for three specimens.

Binder type	35/50	35/50 R	35/50 F	10/40-65	25/55-60	25/55-80
Initial load,						
mean value, [kN]	4.862	5.684	5.094	5.374	5.607	4.726
[lbs]	1093.0	1277.8	1145.3	1199.2	1260.5	1062.4
st. deviation [kN]	0.155	0.038	0.132	0.115	0.314	0.324
[lbs]	34.8	8.6	29.8	36.1	70.5	72.9
COV, [%]	3.2	0.7	2.6	2.1	5.6	6.9
Cycles to failure,						
mean value, [-]	552	120	433	241	854	1069
st. deviation	131	69	102	24	470	203
COV, [%]	26.7	57.5	23.7	9.8	55.0	19.0
Critical fracture energy, G_C						
mean value, [kN-mm/mm^2]	0.000705	0.000815	0.000727	0.000764	0.000765	0.000668
[lbs-in./in.^{2}]	4.03	4.65	4.15	4.36	4.37	3.82
st, deviation [kN-mm/mm^2]	0.000029	0.000016	0.000016	0.000038	0.000022	0.000038
[lbs-in./in.^{2}]	0.16	0.09	0.09	0.22	0.12	0.22
COV, [%]	4.1	2.0	2.1	5.0	2.9	5.7
Crack resistance index, β, (Crack progression rate)						
mean value, [-]	90.68	70.36	91.05	84.60	94.87	88.44
	(0.32)	(0.47)	(0.32)	(0.37)	(0.29)	(0.34)
st. deviation	2.96	2.85	2.18	2.93	1.68	6.16
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.05)
COV, [%]	3.26	4.05	2.40	3.46	1.77	6.97

In terms of the first basic criterion (the number of cycles to failure), only mixture with neat bitumen 35/50 modified with rubber and mixture with polymer-modified bitumen 10/40-65 (which in fact is regarded as a hard polymer-modified bitumen) did not meet the requirements, because for both of these mixtures the numbers of cycles to failure was below 300. The addition of rubber to neat bitumen 35/50 caused a significant decrease in number of cycles to failure in comparison with pure neat bitumen 35/50, whereas in case of addition of polymer fibres to the mixture with the same neat bitumen 35/50, the decrease in this value was only minor.

By using the criterion based on critical fracture energy calculated after the first cycle it can be noted that the lowest resistance to reflective cracking was obtained for the mixture with high modified bitumen 25/55-80, and the highest resistance was observed in case of the mixtures that also contained neat bitumen 35/50, but with the addition of rubber.

In terms of the third criterion that characterizes asphalt mixtures in respect to abilities to attenuate the crack which has already occurred, best performance was achieved with asphalt mixture with polymer-modified bitumen 25/55-60. The lowest results in this case were obtained for mixture with neat bitumen 35/50 with the addition of rubber. But it can be also concluded that the overall results for this criterion (combining both cracking toughness and abilities to attenuate the crack) were good for all tested asphalt mixtures and all of them can be qualified as having good anti-cracking properties. It should be also noted that the coefficient of variation was low and at the acceptable level for values calculated for second and third criterion, whereas the coefficient of variation for number of cycles to failure (which is used in the first, basic criterion) was much higher (see Tab. 5).

Graphical interpretation of cracking initiation and cracking propagation properties of tested mixes is presented in Fig. 8.

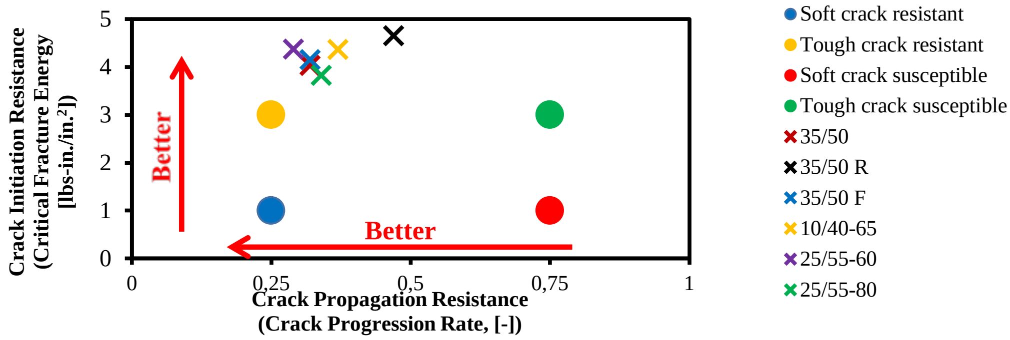

Figure 8. Graphical interpretation of cracking resistance.

6. Conclusions

The type of bitumen that was used in tested asphalt mixtures had significant influence on their cracking resistance.

Polymer-modified bitumen 25/55-60 and highly polymer-modified bitumen 25/55-80 increased resistance of asphalt mixture to cracking. Mixtures with these binders achieved the best results. Polymer-modified bitumen 10/40-65, which was the hardest one in comparison with 25/55-60 and 25/55-80, achieved worse results, even when compared with neat bitumen 35/50. In this case, the overall stiffness of the bitumen was responsible for a decrease in anti-cracking properties.

Asphalt mixture with polymer-modified bitumen 25/55-60 had higher critical fracture energy and better resistance to crack propagation than the mixture with highly polymer-modified bitumen 25/55-80. On the other hand, the latter mixture had better performance in terms of number of cycles to failure.

The addition of polymer fibres did not affect cracking properties in a positive way. Also, the addition of rubber in fact decreased the anti-cracking properties. The mixture with neat bitumen 35/50 modified with ground rubber in most cases performed worse than even the neat bitumen 35/50.

On the basis of the obtained results a following ranking of asphalt mixtures and their cracking resistance can be presented: 1 (the best performance) – 25/55-80 and 25/55-60, 2 – 35/50 and 35/50 F, 3 – 10/40-65, 4 (the worst performance) – 35/50 R.

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