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INDIRECT TENSILE TEST AS A SIMPLE METHOD FOR RUT RESISTANCE EVALUATION OF ASPHALT CONCRETE

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The paper presents the dependence of ITS results at the elevated temperature (40°C) on rutting parameters, i.e. proportional rut depth (PRD_{AIR}) and wheel tracking speed (WTS_{AIR}), obtained at the temperature of 60°C. The asphalt mixture samples were prepared in the gyratory compactor, but ITS tests were conducted with typical Marshall press, at a loading rate of 50 mm/min. Correlation analyses show a strong relationships between ITS results and rutting parameters, whereby the correlation coefficients obtained are higher for the PRD_{AIR} parameter (r = -0.88) than WTS_{AIR} (r = -0.81). Using the obtained regression functions, the prediction limits as well as confidence limits were calculated, which allowed to develop criteria for assessing resistance to rutting on the basis of ITS test, and taking into account the technical requirements in Poland.

Keywords: asphalt concrete (AC), indirect tensile strength (ITS), proportional rut depth (PRD), wheel tracking speed (WTS), permanent deformation of the asphalt pavement

1. INTRODUCTION

The resistance of the asphalt mixture to permanent deformations is one of the basic features that must be ensured at the design stage of mixture composition. The permanent deformation resistance of asphalt mixes is usually evaluated on the characteristics of binder and mix, tested in the laboratory, in accelerated test equipment or in real pavement sections. To verify the resistance to permanent deformation of asphalt mixtures in laboratory various methods are currently used, which

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include different wheel tracking tests (WTT), flow number (FN), flow time (FT), asphalt pavement analyzer (APA), repeated load permanent deformation (RLPD), dynamic modulus (DM), etc. Al-Khatebb et al. [1] found that the FN test results showed better fitting to the expected trend than the dynamic creep test results. On the other hand Zhang et al. [10] conducted a comparative evaluation of the FN, DM and RLPD tests, found that the FN Index, in contrast to the classical FN (cycles) parameter, exhibited a better correlation with results of both the DM and RLPD tests. Xu et al. [8] carried out the partial triaxial test (PTT), and stated that a strong correlation was found between the strain slope value at the second stage in the PTT and the total rut depth in the WTT. In the work of Radhakrishnan et al. [7], a strong correlation was observed between the time lag in the resilient modulus test and the rut depth measured in the wheel tracking test. In European countries, the most common study of HMA resistance to the permanent deformation is the rutting test. For the preparation of samples and the execution of the rutting test, a large amount of mixture as well as special technical equipment is needed, which also affects the cost of the test. Therefore, this research was carried out to indicate a simple test that will allow faster, easier and cheaper assessment of the potential resistance of asphalt mixtures to the permanent deformation. According to the results of work conducted by Christensen et al. [2], such testing may be the indirect tensile strength (ITS) on cylindrical samples, with appropriate adjustment of the test temperature and the speed of piston travel. The exemplary recommended conditions of the ITS test according to the work [2] is the temperature 20°C lower than the critical pavement temperature due to permanent deformation at the piston's speed in the press equal to 3.75 mm / min. In the following years, Christensen and Bonaquist [3] modified the testing conditions so that one could use the popular Marshall press with a piston speed of 50 mm / min, proposing a correction by increasing the test temperature by 10°C (10°C below the critical asphalt pavement temperature). A very high coefficient of determination was obtained, describing the relationship between the test conditions given above ($R^2 = 0.99$). Then, basing on the results of the study, the authors [3] developed criteria for the requirements for the indirect tensile strength of the asphalt mixture samples depending on the design traffic load and the vehicle speed. Research on the correlation between asphalt mixes indirect tensile strength and the rut resistance was also carried out by Zaniewski and Srinivasan [9] as well as Khousla and Harikrishnan [5]. In both of the above reports it was found that there is a strong relationship between the indirect tensile strength of asphalt mixes samples and their resistance to permanent deformation. The reverse results were obtained by Kruger and Horak [6], statistical analysis revealed poor correlation between the ITS, measured with Marshall press at a temperature of 25°C, and the rut results ($R^2 = 0.17$). Isailovic, Wistuba and Augusto [4] measured permanent deformation by triaxial test at a temperature of 50°C and indirect tensile fatigue test at 20°C. The poor relationship obtained in the above works [4, 6] can be explained by the use of a relatively low ITS test temperature.

In this work an attempt was made to develop a relationship between the indirect tensile strength under the elevated temperature conditions, tested on samples compacted in the gyratory press, and HMA parameters of resistance to rutting, tested in accordance with the technical requirements in Poland [12], i.e. in a small wheel tracker. Additionally, on the basis of the obtained functional dependences, considering the confidence limit and the limit of estimation prediction, propositions of ITS requirements at 40°C were given as a criterion for HMA's resistance to permanent deformations in relation to technical requirements [12].

2. Materials and methods

The scope of the tests comprised 21 asphalt concrete mixes, intended for base, binder and wearing courses, with nominal grain size: 0/22 mm, 0/16 mm and 0/8 mm. A various binder, i.e. paving bitumen (35/50 or 50/70), polymer modified (25/55-60 or 45/80-55) or rubber modified were used in this mixtures. Besides, in same mixtures, the addition of reclaimed asphalt pavement (RAP) or reclaimed asphalt shingles (RAS) was used. A detailed specification of the composition and physical properties of the tested asphalt concrete mixes are given in Table 1.

Table 1. Composition and physical characteristics of AC samples compacted in a gyratory press

O.N.	AC Mark	Bitumen Content [%]	Density [g/cm^3]	Bulk Density [g/cm^3]	Air Voids [%]	VMA [%]	VFB [%]
1	AC 16 W 35/50	4.4	2.620	2.602	0.7	12.1	94.3
2	AC 16 W PMB 25/55-60	4.4	2.621	2.601	0.8	12.2	93.7
3	AC 16 W PMB 25/55-60	4.5	2.537	2.504	1.3	12.6	89.7
4	AC 16 W PMB +RAP	4.5	2.561	2.529	1.2	12.6	90.1
5	AC 16 W PAT+RAP	4.5	2.553	2.514	1.5	12.8	88.1
6	AC 16 W PAT+RAP+JUV	4.5	2.539	2.529	0.4	11.8	96.7
7	AC 16 W 35/50	4.4	2.618	2.607	0.4	11.9	96.5
8	AC 16 W 35/50	4.4	2.618	2.603	0.6	12.0	95.2
9	AC 22 P 35/50	4.0	2.626	2.529	3.7	13.8	73.3
10	AC 22 P 35/50	3.9	2.605	2.529	2.9	12.8	77.2
11	AC 22 P 35/50	4.0	2.519	2.49	1.2	11.1	89.6
12	AC 16 W PMB 25/55-60	4.4	2.613	2.605	0.3	11.8	97.4
13	AC 22 P 35/50	3.8	2.626	2.529	3.7	13.3	72.2
14	AC 16 W 35/50	4.5	2.557	2.502	2.2	13.4	84.0
15	AC 16 W 35/50	4.5	2.561	2.525	1.4	12.8	89.0
16	AC 16 W 50/70	4.5	2.564	2.535	1.1	12.5	91.0
17	AC 16 W 50/70+1%RAS	4.4	2.619	2.564	2.1	13.4	84.3
18	AC 16 W 50/70+1%RAS	4.4	2.626	2.601	1.0	12.4	92.3
19	AC 16 W 35/50	4.4	2.595	2.564	1.2	12.5	90.4
20	AC 8 S PMB 45/80-55	5.7	2.601	2.584	0.7	15.4	95.8
21	AC 16 W 35/50+1%RAS	4.4	2.626	2.614	0.5	12.0	96.2

For all of the tested asphalt mixtures, test samples were prepared as follows:

– Samples with a diameter of 100 mm and a height of 100 mm (± 2.5 mm), compacted with constant energy in a gyratory press according to PN-EN 12697-31 [16] up to 200 rotations, which were then cut in half for test specimens with an approximate height of 50 mm.
– Plate samples with dimensions 305mm x 305mm and height 40-60 mm (depending on the grain size of the mix), compacted with roller compactor according to PN-EN 12697-33 [17] to 99% (± 1%) bulk density determined according to the Marshall method [15].

All plate samples were used to study rutting in a small apparatus according to PN-EN 12697-22 [13], method B in air, at 60°C, 2 plates were prepared for each mix. As a result of the test, the proportional rut depth expressed in percentage (PRD_{AIR}) and the speed of rut increase in the second test phase expressed in mm/1000 load cycles (WTS_{AIR}) were determined.

Cylindrical samples were used for testing indirect tensile strength (ITS) according to PN-EN 12607-23 [14], using the Marshall press at a piston speed of 50 mm/min, at the temperature of 40°C. The accepted ITS test parameters are consistent with those given in [3]. For each mixture, 2-6 samples were tested (coefficient of variation of ITS results below 10% were obtained), the force was recorded as a function of piston displacement until the sample was destroyed and the indirect tensile strength was calculated according to Eq. (2.1).

$$ITS = \frac{2*P}{\pi*D*L} * 10^6 \tag{2.1}$$

where:

ITS - indirect tensile strength in kPa, rounded up to three significant digits, P - peak load value in kN, rounded up to three significant digits, D - sample diameter in mm, rounded to the decimal, L - sample length in mm, rounded to the decimal.

3. Results and discussion

The average values of rutting test parameters at 60°C and indirect tensile strength at 40°C are given in Table 2. Statistical analyses of the results were started by determining the Spearman linear correlation between the rutting parameters (PRD and WTS), the ITS results and AC sample composition parameters such as: bitumen content (B), air voids content in asphalt mixture (VIM), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB). Among the above-mentioned parameters, significant correlation coefficients showed only the ITS results at 40°C, this relation is negative and the coefficients are, respectively: -0.82 for the WTS parameter and -0.88 for the PRD parameter. Properties related to the composition of AC showed no linear relationship with rutting parameters, i.e. the absolute values of correlation coefficients ranged from 0.04 to 0.30. Detailed results of correlation analyses, including correlation coefficients and probability values, testing the statistical significance of estimated correlations, are given in Table 3.

Table 2. Results of rutting and ITS for AC samples

O.N.	AC Mark	PRD [%]	WTS [mm/1000 cycles]	ITS (40°C) [kPa]
1	AC 16 W 35/50	4.9	0.070	448
2	AC 16 W PMB 25/55-60	3.4	0.030	722
3	AC 16W PMB 25/55-60	3.3	0.040	819
4	AC 16 W PMB +RAP	3.0	0.038	849
5	AC 16 W PAT+RAP	2.4	0.030	763
6	AC 16 W PAT+RAP+JUV	3.3	0.039	669
7	AC 16 W 35/50	7.4	0.173	455
8	AC 16 W 35/50	6.3	0.135	451
9	AC 22 P 35/50	7.9	0.173	456
10	AC 22 P 35/50	8.0	0.182	432
11	AC 22 P 35/50	4.5	0.052	579
12	AC 16 W PMB 25/55-60	3.3	0.048	716
13	AC 22 P 35/50	6.3	0.152	533
14	AC 16 W 35/50	5.8	0.107	564
15	AC 16 W 35/50	3.5	0.050	761
16	AC 16 W 50/70	5.0	0.099	643
17	AC 16 W 50/70+1%RAS	9.2	0.217	378
18	AC 16 W 50/70+1%RAS	8.5	0.233	464
19	AC 16 W 35/50	2.7	0.041	908
20	AC 8 S PMB 45/80-55	5.8	0.084	649
21	AC 16 W 35/50+1%RAS	5.3	0.094	519

Table 3. Results of correlation coefficients and their statistical significance tests (P-value)

AC parameters	VIM	VFB	VMA	ITS	PRD	WTS
B	-0.534 (0.013)	0.576 (0.006)	0.493 (0.023)	0.296 (0.192)	0.203 (0.378)	0.276 (0.226)
VIM	-	-0.997 (0.000)	0.459 (0.037)	-0.269 (0.238)	0.421 (0.057)	0.435 (0.049)
VFB		-	0.407 (0.067)	0.253 (0.269)	-0.398 (0.074)	-0.418 (0.059)
VMA			-	-0.043 (0.855)	0.300 (0.185)	0.243 (0.290)
ITS				-	-0.883 (0.000)	-0.818 (0.000)
PRD					-	0.971 (0.000)

Using regression function in Statgraphics program [11] relations between the indirect tensile strength at 40°C and 60°C rutting parameters (PRD and WTS) were determined. The multiplicative model has shown the best fit for both the PRD and the WTS parameters, which is compatible with Christensen and Bonaquist [3], a detailed comparison of model matching is given in Table 4.

Table 4. Comparison of alternative regression models

O.N.	Model	For PRD parameter		For WTS parameter	
		Correlation	R-squared [%]	Correlation	R-squared [%]
1	Multiplicative	-0.910	82.7	-0.866	75.1
2	Exponential	-0.906	82.0	-0.855	73.1
3	Recipropal-X	0.905	81.8	0.853	72.8
4	S-curve	0.902	81.3	0.865	74.8
5	Recipropal-Y	0.899	80.9	0.833	69.4
6	Logarithmic-X	-0.899	80.8	-0.841	70.7
7	Square root-Y	-0.898	80.8	-0.843	71.1
8	Square root-X	-0.892	79.6	-0.831	69.0
9	Linear	-0.883	77.9	-0.818	66.8
10	Double reciprocal	-0.872	76.1	-0.823	67.7
11	Logistic	No fit		-0.853	72.8
12	Log probit	No fit		-0.865	74.8

In the case of the tested mixtures, a high determination coefficient was observed between ITS at 40°C with rutting parameters, with a better fit for the PRD (R^2 = 82%) than for the WTS parameter (R^2 = 75%). The obtained function dependence, representing a PRD value is presented in Eq. (3.1) but regression model and ANOVA table for multiplicative regression are shown in Table 5 and in Table 6 respectively. This relationship is statistically significant and it explains 82% of the variability of the results. Moreover, from Table 6 it can be seen that P-value of the regression model is very much less than 0.05, indicating that at 95% confidence level it can be concluded that there exists a strong relation between the indirect tensile strength value and the proportional rut depth in AC mixtures.

$$PRD_{AIR} = 48220 * ITS^{-1.443} \tag{3.1}$$

Correlation coefficient – R = -0.9095

R-squared = 82.71 %

R-squared (adjusted for d.f.) = 81.8 %

Standard Error of Estimation - SSE = 0.175

Mean Absolute Error - MAE = 0.132

Durbin-Watson Statistics = 1.53 > 1,4 – autocorrelation of non-existing residuals

Table 5. Parameter estimates of multiplicative regression model (PRD)

Parameter	Estimate	Standard Error	T-stat	P-value
Intercept*	10.7835	0.9665	11.1579	0.0000
Slope	-1.4433	0.15138	-9.5344	0.0000

* Intercept = ln(a)

Table 6. Analysis of variance table for PRD regression model

Source	DF (Degree of Freedom)	SS (Sum of Squares)	MS (Mean Square)	F-stat	P-value
Model	1	2.7734	2.7734	90.90	0.0000
Residual	19	0.5797	0.0305		
Total	20	3.3531			

The formula for the WTS parameter is described by Eq. (3.2), regression model and ANOVA table for multiplicative regression are shown in Table 7 and in Table 8 respectively. Obtained relationship is statistically significant and it explains 74% of the variability of the results. Moreover, from Table 8 it can be seen that P-value of the regression model is very much less than 0.05 (a level critical value), indicating that at 95% confidence level it can be concluded that there exists a strong relation between the indirect tensile strength value and the wheel tracking speed in AC mixtures.

(3.2) $$WTS_{AIR} = 198925 * ITS^{-2.309}$$

Correlation coefficient - R= -0.8663

R-squared = 75.05 %

R-squared (adjusted for d.f.) = 73.73 %

Standard error of estimation - SSE = 0.352

Mean absolute error - MAE = 0.274

Durbin-Watson statistics = 1.15 < 1,4 – possible autocorrelation of residuals

Table 7. Parameter estimates of multiplicative regression model (WTS)

Parameter	Estimate	Standard Error	T-stat	P-value
Intercept	12.2007	1.9498	6.2575	0.0000
Slope	-2.3086	0.30540	-7.5593	0.0000

* Intercept = ln(a)

Table 8. Analysis of variance table for WTS regression model

Source	DF (Degree of Freedom)	SS (Sum of Squares)	MS (Mean Square)	F-stat	P-value
Model	1	7.0957	7.0957	57.14	0.0000
Residual	19	2.3593	0.1242		
Total	20	9.4550			

In the next step of the analysis, the confidence limits (internal lines) and prediction limits (outside lines) for the PRD and WTS were determined, assuming the probability of 95%. These model plots (middle line) are shown in Fig. 1 (PRD) and in Fig. 2 (WTS), whereas their fitting to the data are given in Fig. 3 and in Fig. 4 respectively.

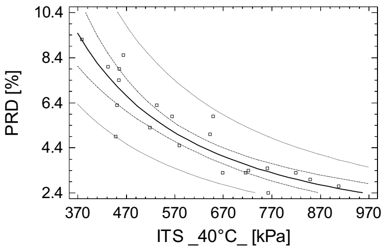

Fig. 1. Dependence between PRD and ITS results for AC samples

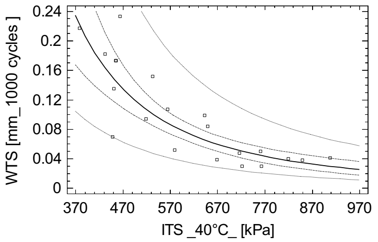

Fig. 2. Dependence between WTS and ITS results for AC samples

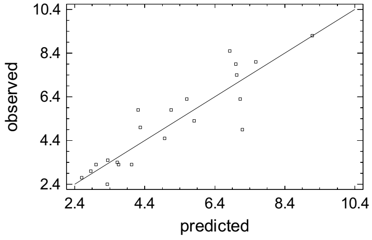

Fig. 3. Relations between observed and predicted PRD value

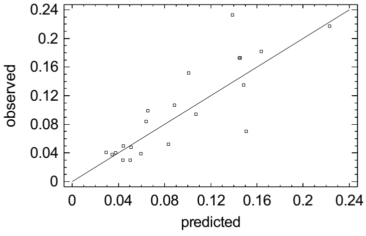

Fig. 4. Relations between observed and predicted WTS value

On the basis of determined functional models, the predicted values of rutting parameters in a certain range were calculated (PRD: 5 – 10%) and WTS (0.10 – 0.30 mm/1000 cycles) along with the determination of prediction limits and confidence limits, with 95% probability. The results are summarized in Table 9 (PRD) and in Table 10 (WTS). Then, the criterion of the ITS values were adopted at 40°C as corresponding to the upper prediction limits for the rutting parameters required by Polish Technical Requirements for Asphalt Mixtures, WT-2 [12] (Table 11). No requirements were given for the wearing coarse, as only one such mixture was tested.

Table 9. Predicted values of ITS for a given PRD values

PRD [%]	Predicted ITS [kPa]	95% prediction limits		95% confidence limits	
		lower	upper	lower	upper
5	578	457	732	550	608
6	521	411	661	492	552
7	477	375	607	445	511
8	442	346	564	408	479
9	413	322	529	376	453
10	389	302	501	350	432

Table 10. Predicted values of ITS for a given WTS values

WTS [mm/1000 cycles]	Predicted ITS [kPa]	95% prediction limits		95% confidence limits	
		lower	upper	lower	upper
0.10	548	413	728	514	584
0.15	480	360	641	442	522
0.20	438	326	588	395	485
0.25	407	301	550	361	458
0.30	384	282	521	336	438

Table 11. Proposal of AC rutting requirements based on ITS at 40°C (95% prediction limits)

Asphalt layer	Traffic category (KR 3-4)				Traffic category (KR 5-7)			
	PRD	WTS	ITS (PRD)	ITS (WTS)	PRD	WTS	ITS (PRD)	ITS (WTS)
base	9	0.30	**529**	521	7	0.15	607	**641**
binder	7	0.15	607	**641**	5	0.10	**732**	728

4. Conclusions

For both rutting parameters (PRD and WTS), a significant linear correlation with indirect tensile strength, determined at 40° C with using a typical Marshall press, was found.

Obtained linear correlation coefficients are negative, i.e. the higher indirect tensile strength the lower values of parameters specifying AC resistance to rutting.

It was noticed that the indirect tensile strength tested at 40°C is a better estimator of the PRD parameter than the WTS parameter, the resulting functional relations explain here: 82% of the variability for the PRD parameter and 75% of the variability for the WTS parameter.

The above analyses confirm earlier American studies [3] that the proposed test, i.e. ITS at 40°C at the piston rate of 50 mm/minute, conducted on samples compacted in a gyratory press, seems to be a good estimation of the resistance of asphalt concrete mix to the permanent deformation damages.

As a continuation of the ITS study, the use of other mixture types as well as samples compacted with a Marshall hammer should be considered, which will popularize the use of this test method.

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17. PN-EN 12697-33 Bituminous Mixtures. Test methods for hot mix asphalt. Specimen preparation by roller compactor.

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BADANIE WYTRZYMAŁOŚCI NA ROZCIĄGANIE POŚREDNIE JAKO PROSTA METODA OCENY ODPORNOŚCI NA KOLEINOWANIE DLA BETONU ASFALTOWEGO

Słowa kluczowe: beton asfaltowy (AC), wytrzymałość na rozciąganie pośrednie (ITS), proporcjonalna głębokość koleiny (PRD), szybkość przyrostu koleiny (WTS), deformacje trwałe nawierzchni asfaltowej

STRESZCZENIE:

Odporność mieszanek mineralno-asfaltowych (MMA) na powstawanie deformacji trwałych jest jednym z podstawowych wymagań, które należy zapewnić podczas projektowania składu mieszanki. Najczęściej stosuje się do tego celu badania koleinowania na laboratoryjnie zagęszczanych próbkach MMA, co wymaga stosunkowo dużych próbek oraz użycia specjalistycznej aparatury, zarówno do zagęszczenia takich próbek jak i samego ich badania. W związku z powyższym, w wielu krajach prowadzone są badania celem wytypowania prostego testu, który można wykonać z wykorzystaniem powszechnie dostępnych w laboratoriach drogowych urządzeń (np. prasa Marshalla), na standardowo przygotowywanych próbkach MMA. Zgodnie z wynikami prac prowadzonych przez Christensena i Bonaquista, Zaniewskiego i Srinivasana jak również Khousla i Harikrishnanna takim badaniem może być wytrzymałość na rozciąganie pośrednie (ITS), przy odpowiednim dostosowaniu temperatury badania jak również szybkości przesuwu tłoka w prasie. Dla celów praktycznych rekomendowane jest użycie standardowej prasy Marshalla o prędkości przesuwu tłoka 50 mm/minutę, przy temperaturze badania równej 40°C. W niniejszej publikacji przedstawiono badania zależności pomiędzy wynikami ITS, przeprowadzonego wg wyżej wymienionych warunków, oraz parametrami koleinowania w małym koleinomierzu w 60°C, tj. proporcjonalną głębokością koleiny (PRD_{AIR}) i szybkością przyrostu koleiny (WTS_{AIR}). Do badania wytrzymałości na rozciąganie pośrednie przeznaczono próbki o średnicy 100 mm zagęszczone w prasie żyratorowej, natomiast do badania koleinowania przygotowano płyty o wymiarach 305 x 305 mm i wysokości 40 mm lub 60 mm, zależnie od uziarnienia badanej MMA. Przebadano łącznie 21 mieszanek betonu asfaltowego przeznaczonego do warstw podbudowy, wiążącej i ścieralnej o uziarnieniach 0/22 mm, 0/16 mm i 0/8 mm. W mieszankach tych stosowano różne asfalty tj.: drogowe niemodyfikowane (35/50 i 50/70), modyfikowane polimerami (PMB 25/55-60, PMB 45/80-55), modyfikowane gumą (wg rozwiązań patentowych). Dodatkowo w niektórych mieszankach stosowano dodatek granulatu asfaltowego (RAP) lub granulatu papy (RAS). Uzyskane wartości średnie dla poszczególnych MMA, dotyczące: ITS, parametrów koleinowania (PRD i WTS), parametrów składu MMA takich jak zawartość lepiszcza, wolne przestrzenie w MMA, wolne przestrzenie w mieszance mineralnej (VMA) oraz wypełnienie wolnych przestrzeni w mieszance mineralnej przez asfalt (VFB), zostały poddane analizom korelacji liniowej. Uzyskane korelacje z parametrami koleinowania okazały się istotne tylko w przypadku wyników ITS, współczynniki korelacji są ujemne i wynoszą odpowiednio: -0.82 dla parametru WTS oraz -0.88 dla parametru PRD. Właściwości opisujące skład betonu asfaltowego uzyskały względem parametrów koleinowania nieistotne współczynniki korelacji, w granicach 0.04 – 0.30. W analizie regresji porównano funkcje opisujące zależność pomiędzy ITS i parametrami koleinowania, najlepsze dopasowania w obu przypadkach uzyskał model iloczynowy, co jest zgodne z wynikami prac Christensena i Bonaquista. Analiza wariancji przy przyjętym poziomie ufności (95%) wykazała, że uzyskane modele są statystycznie istotne, skorygowane współczynniki determinacji wyniosły: 82% dla parametru PRD i 74% dla parametru WTS. Opierając się na uzyskanych zależnościach funkcyjnych wyznaczono granice ufności i granice oszacowania dla przyjętych przedziałów wartości PRD (5 – 10 %) i WTS (0.10 – 0.30 mm/1000 cykli). Następnie odnosząc się do wymaganych poziomów parametrów koleinowania podanych w Wymaganiach Technicznych WT-2 2014, dla konkretnej lokalizacji warstwy asfaltowej w

nawierzchni (podbudowa, warstwa wiążąca) oraz zakresu kategorii ruchu (KR3-4 lub KR5-7), wyznaczono kryteria dla wytrzymałości na rozciąganie pośrednie w odniesieniu do obu parametrów koleinowania tj. PRD i WTS. Zaproponowane kryteria wyliczono jako górną granicę przedziału oszacowania z prawdopodobieństwem 95%, co jest rozwiązaniem bardziej bezpiecznym niż przyjęcie jako kryterium górnej granicy przedziału ufności. W przedstawionych analizach pominięto wyznaczenie kryteriów dla warstwy ścieralnej, ponieważ badaniami objęto tylko jedną taką mieszankę. Jako kontynuację badań ITS należy rozważyć rozszerzenie badań także na inne mieszanki, zwłaszcza przeznaczone do warstwy ścieralnej, oraz użycie próbek MMA zagęszczonych za pomocą ubijaka Marshalla, co upowszechni zastosowanie przedmiotowej metody badawczej.

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