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COMPARISON OF METHODS OF TESTING RESISTANCE TO PERMANENT DEFORMATION OF MASTIC ASPHALT

The most common method to assess the resilience of mastic asphalt to permanent deformation is the static stamp indentation. The test is relatively simple and fast, but does not sufficiently differentiate of hard mixes. The paper presents a method to improve assess of asphalt concrete mixtures resistance on plastic deformations – indentation with dynamic stamp. The article describes the methodology of the test and interpretation of the results. Our study was performed on a mixture of mastic asphalt MA8 with the addition of natural asphalt TLA (Trinidad Lake Asphalt). The study achieved a sufficient correlation between the results of the static and dynamic test. It was also found that the dynamic indentation differentiates more detailed mixtures in terms of resistance to permanent deformation than static indentation test.

Keywords: static indentation pin, dynamic indentation pin, mastic asphalt, deformation

1. Introduction

Mastic asphalt is a bituminous mix with different properties from the commonly used asphalt concretes and SMA mixes. The high content of bitumen and filler makes the mixture self-compacting and waterproof. As a result, it is used for protective layers on bridges.

Analyzing the mastic asphalt requirements included in standard PN-EN 13108-6 [11], it can be concluded that this document specifies only a few mixture properties. In addition to the requirements concerning the quality of production and resistance to de-icing agents, fuel and abrasion by tires, only provisions regarding resistance to permanent deformation are marked. Test for resistance to permanent deformation can be performed under static or dynamic loading. In Polish requirements of WT2-2014 [13], static load indentation test was used to assess this property. They are made in a penetrometer that allows to

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apply an initial load of 25 N, then after 10 minutes an additional load of 500 N giving a final load of 525 N. It is transmitted through a cylindrical indentor pins with the area of 500 mm^2. During the test the sample is kept in a water bath at 40°C. The indentation after 30 minutes and the indentation increment after next 30 minutes are reported, each time as the average of two samples [9].

The test of penetration with the static load is easy and relatively quick, yet it does not sufficiently differentiate mastic asphalt mixtures, especially the harder ones [3]. In the penetration range of 1-3 mm, some mixtures, despite meeting the requirements, may have poor rutting resistance during operation [3]. For proper assessment of mixtures more test methods were developed. One of them is the dynamic indentation test. This method was developed in Germany. Based on the tests results, a good correlation was found between the results of laboratory tests and the depth of the rut in the pavement, as shown in Figure 1.

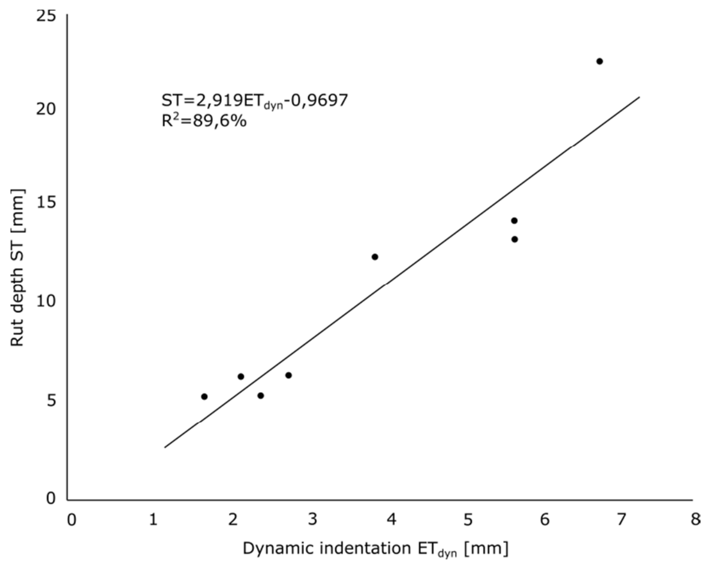

Fig. 1. Relationship between rut depth and dynamic indentation for bridge pavement for the various configurations of mastic asphalt type GA 0/11 [3]

Dynamic indentation test is performed in accordance with PN-EN 12697-25 method A [12], with minor modifications. Cylindrical samples 150 mm with diameter and 60 mm high are used for the test. The sample base planes are parallel to each other. The load is applied through a steel indentor pins with the area of 2500 mm^2 (diameter 56,4mm), cyclically with the following parameters [4, 6, 10, 12]:

- maximum load level: 0.875 kN (corresponds to the sample load 0.35 N/mm^2);
- minimum load level: 0.2 kN (corresponds to the sample load 0.08 N/mm^2);
- pulse duration: 0.2 s;

- rest period: 1.5 s;
- cycle time: 1.7 s;
- load curve shape: haversine.

The test is carried out in air conditions, maintaining a constant sample temperature of 50 ± 0.3°C. The shape of the load curve is shown in Figure 2.

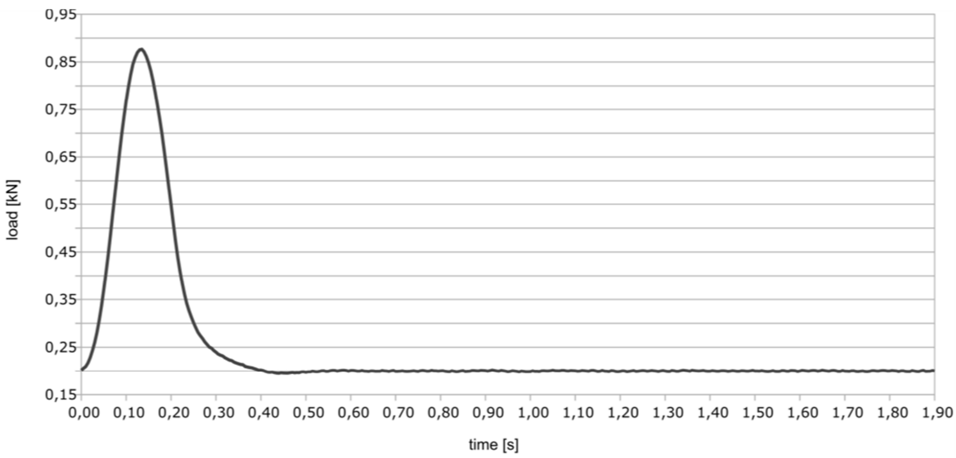

Fig. 2. Shape of the load curve in test of dynamic indentation

During the test, the change in height of the sample caused by the applied load is measured. As the result of the test, the indentation after 2500 and 5000 cycles is reported. The large sample diameter compared to the indentor pins diameter means that a steel mold is not needed for lateral restraint of the sample (as is the case with static indentation). At the same time, test conditions similar to real conditions are obtained, where horizontal deformation around the loaded place is reduced [3]. According to the standard [11], this test is recommended for mastic asphalt mixtures with mix size up to 11 mm and if the penetration under static load is less than 2.5 mm. Figure 3 shows an example of the test result. Line 1 is a mixture with good resistance to permanent deformation, while line 2 is a mixture with poor resistance. The similarity to the result of the rutting test is noteworthy, where at the beginning there is a large rut increase, followed by stabilization of this increase.

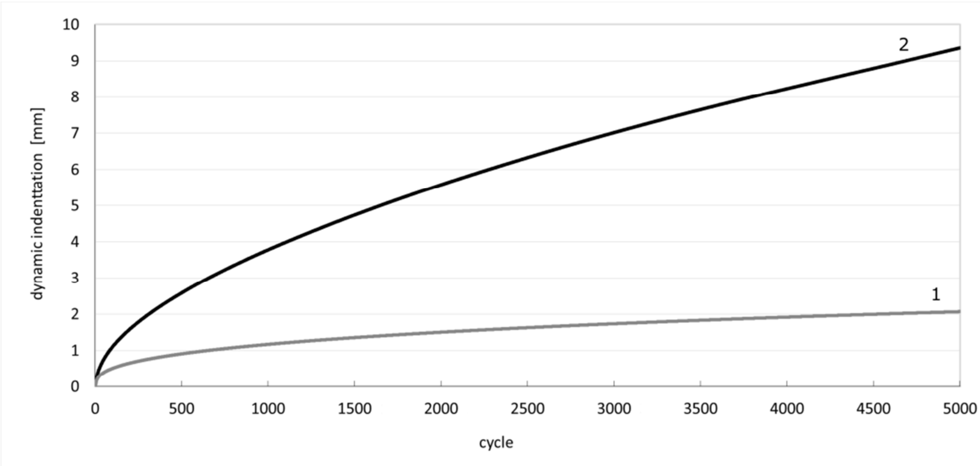

Fig. 3. Example of indentation curve in test of dynamic indentation stamp

Based on following experiments [3], it was found that mastic asphalts with penetration under dynamic load greater than 3 mm are not suitable for surfaces under high traffic loads. It was also noticed that mixtures with penetration at static load in the order of 1-1,5 mm have obtained dynamic test results in the wide range of 0,5-4,0 mm. Thus, doing the dynamic indentation test there is a possibility to reject incorrect mixtures. Moreover, there exists high sensitivity to changes in the composition of the mastic asphalt mixture, which allow to develop the most optimal mix formula.

2. Results

In the own research carried out under the grant[3] penetration markings of mastic asphalt with static and dynamic indentation were made. The MA8 mix with 35/50 road asphalt was used in an amount of 7 and 8 % m/m in relation to the asphalt mix and with the addition of natural asphalt Trinidad Lake Asphalt (TLA) in an amount of 0, 10 and 20% in relation to the weight of the pure bitumen. Table 1 presents the composition of the aggregate and bituminous mixtures. The mixtures were tested before and after simulated short term aging at 180 and 220 ^{o}C. The loose asphalt mix was laid out on a metal tray in a layer about 30 mm thick, and then placed in an oven with forced air circulation for 4 hours, with the mix being mingled every hour to ensure uniform aging conditions throughout its volume. The simulated aging temperatures were set at 180 and 220 ^{o}C as the delivery mix temperature at construction, including reduction of the base bitumen resulting from addition of the TLA.

[3] Umowa nr U-664-DS/M pt.: „*Ocena odporności mieszanek asfaltu lanego na deformacje trwałe w aspekcie starzenia krótko- i długoterminowego.*”

Table 1. Composition of the mixture of mastic asphalt

Content	Aggregate mix [%]	Asphalt mix A [%]	Asphalt mix B [%]
Bitumen 35/50	---	8.0	7.0
Filler	36.0	33.1	33.5
Basalt 0/2	32.0	29.4	29.8
Amphibolite 2/5	21.0	19.3	19.5
Amphibolite 5/8	11.0	10.1	10.2

Eighteen mix variants were tested, which allowed to obtain a wide range of static penetration. Figure 4 presents the designation of tested mix variants.

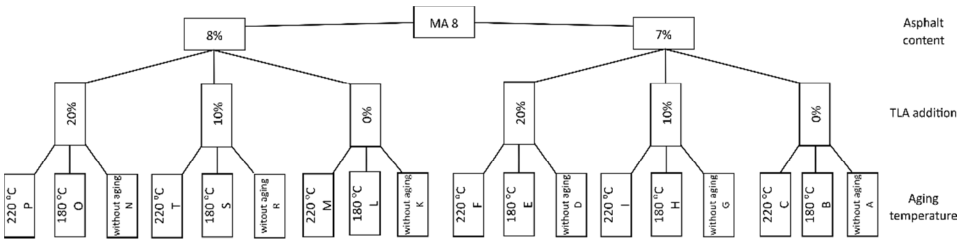

Fig. 4. Tests plan and sample symbols

The static indentation test was carried out in accordance with PN-EN 12697-20 [11] on cylindrical samples h <d formed at 220°C, while the dynamic indentation test was carried out in accordance with PN-EN 12697-25 [10], PN- EN 13108-20 [12] and information included in the articles [4, 6] on cylindrical samples with a diameter of 150 mm cut into slices about 60 mm high. A suitably adapted UTM-25 device was used for the tests. In the static test, the indentation was read after 30 and 60 minutes, while in the dynamic test the results were noted after 2500 and 5000 cycles. Before the dynamic test, the samples were thermostated for 4 hours at the test temperature and then subjected to an initial static load of 10 kPa. Figure 5 shows a sample with the indentor pins and measuring system installed. The indentation in the sample were obtained as the average of three values: two of the LVDT gauge based on a plate attached to the pins and one of the actuator displacement gauge. In addition to the method of applying the force and temperature of the test, the way the sample surface is prepared for testing is noteworthy. In the case of cubic or cylindrical samples for the static indentation test, the sample is not subjected to any treatment, therefore the coarse aggregate grains are submerged in asphalt mastic and do not have direct contact with the surface of the pins. However, in the case of the dynamic indentation, the surface of the sample is sanded with a saw when cutting the

sample into slices. This means that the loading punch has direct contact with the sawdust aggregate. In the case of a sample of uncut grains, the aggregates are point-loaded and can be "softly" shifted or pressed through a deepening punch. In the case of a dynamic indentation, aggregate grains are loaded on a larger surface, which means that they can be broken or tilted, sometimes increasing the contact area of the punch with the sample [1], as illustrated in Figure 6.

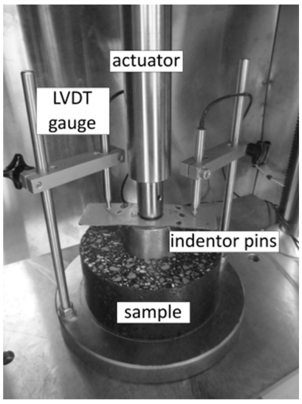

Fig. 5. View a set of measurement to study the dynamic indentation

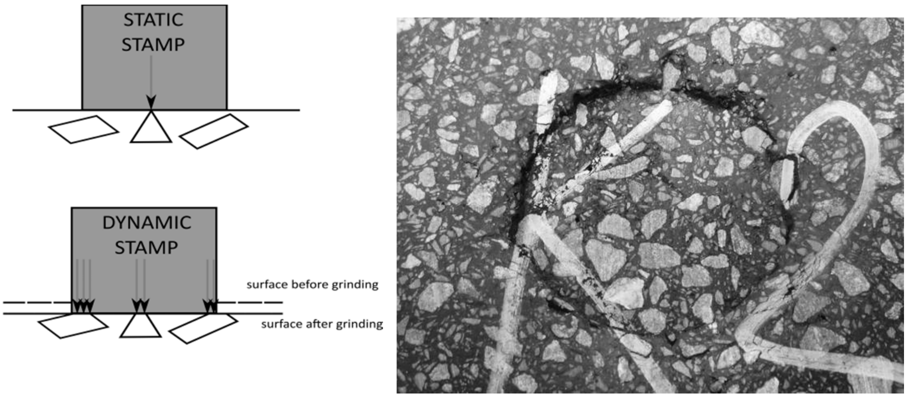

Fig. 6. Difference in samples of ground load and uncut and example spalling grains and thick on the surface of the sample after testing dynamic indentation

The obtained test results are presented in Table 2 and Figures 7, 8 and 9. Equations for calculating the results for both methods were also proposed. The quadratic equation for penetration has a better coefficient of determination than the linear equation. The static and dynamic indentation test results obtained were compared in the middle of the assumed test cycle and after the end of the cycle. Before calculating the regression curve, outgoing observations that could affect the regression curve were removed from the sample set based on the values of studentized residuals. In this way, sample M was removed from further analyzis (marked as "outlier" in figures 7, 8 and 9). After its removal, no outliers were found in the sample set. A very good fit of the model to the calculation results was found for both curves. A Pearson r-correlation coefficient was calculated using a spreadsheet. For penetration after 2500 cycles, the result was r_{2500} = 0.984, while for penetration after 5000 cycles this factor is r_{5000} = 0.987. This means that there is a very strong relationship between the results of the penetration in the static test and the results in the dynamic test. Comparison of the results shows that the penetration values after 2500 and 5000 cycles are about 1,5 times higher than analogous in a static indentation test after 30 and 60 minutes, the penetration increases are about 3.8 times higher than in a static indentation test. The calculated r-Pearson correlation coefficient for the penetration increase is $r_{2500\text{-}5000}$ = 0.981. Therefore, a very strong relationship between the results of these studies is observed.

Table 2. Results of the study of penetration stamp static and dynamic

Sample	Indentation [mm]				Indentation increment [mm]	
	30 min	60 min	2500 cyc.	5000 cyc.	Static	Dynamic
A	1.56	1.76	1.61	2.10	0.20	0.49
B	0.82	0.90	1.12	1.43	0.08	0.31
C	0.53	0.57	0.47	0.55	0.04	0.08
D	0.44	0.47	0.42	0.50	0.03	0.08
E	0.52	0.57	0.31	0.37	0.05	0.07
F	0.42	0.45	0.56	0.63	0.03	0.07
G	0.84	0.92	1.32	1.72	0.08	0.40
H	0.66	0.72	0.31	0.38	0.06	0.07
I	0.46	0.49	0.49	0.56	0.03	0.07
K	3.79	4.5	6.45	9.09	0.71	2.64
L	3.06	3.54	4.82	6.87	0.48	2.05
M	2.80	3.31	2.05	2.94	0.51	0.89
N	1.29	1.45	2.34	3.01	0.16	0.67
O	1.54	1.77	1.76	2.32	0.23	0.56
R	2.58	3.03	3.91	5.78	0.45	1.87
S	1.79	2.08	2.49	3.45	0.29	0.96
T	1.57	1.80	2.32	3.24	0.23	0.92

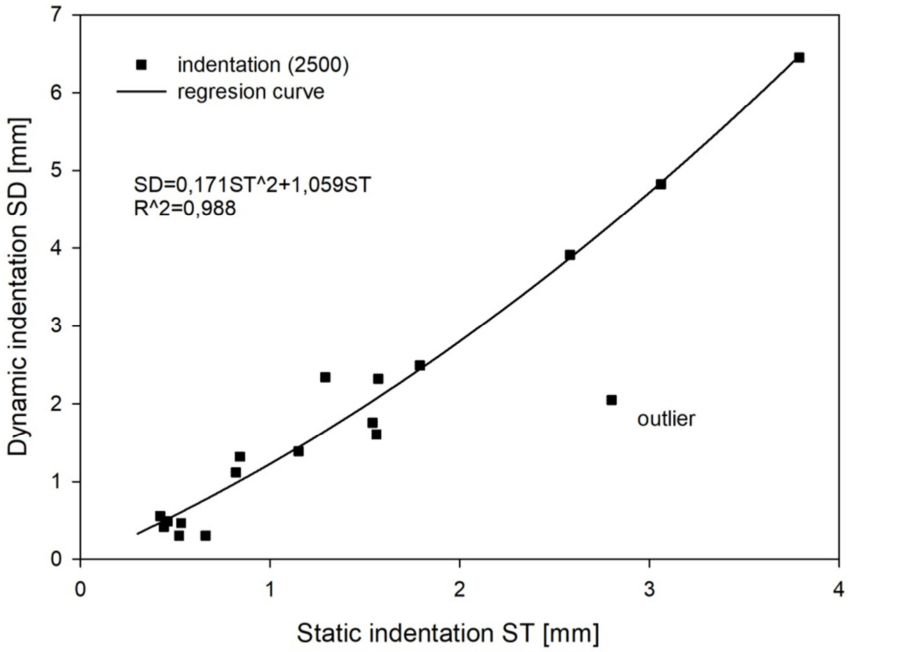

Fig. 7. Dependence of the penetration of the dynamic indentation of the static indentation for 2500 cycles

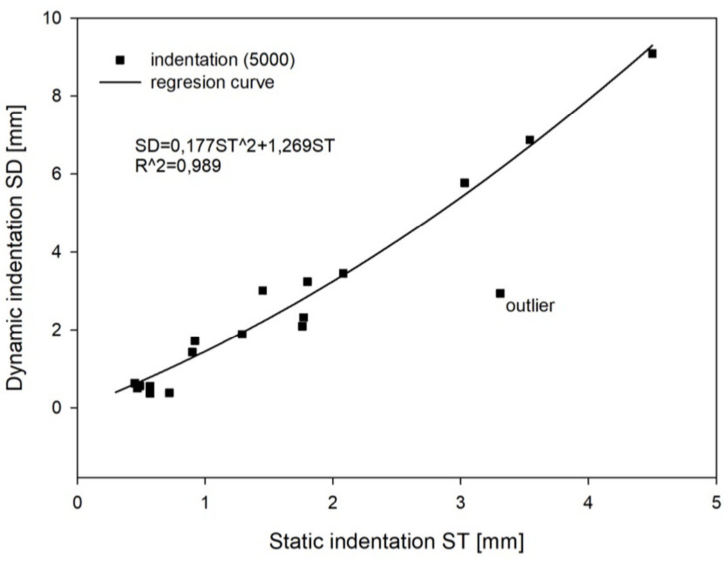

Fig. 8. Dependence of the penetration of the dynamic indentation of the static indentation for 5000 cycles

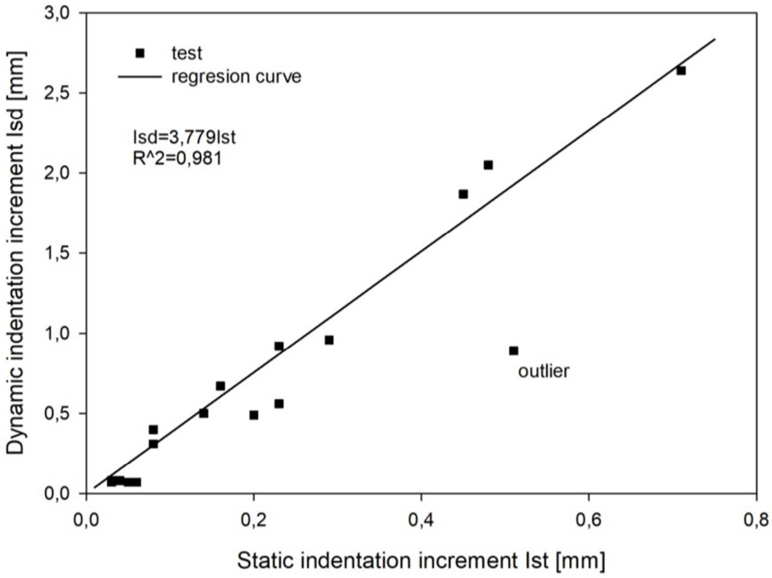

Fig. 9. Dependence of the dynamic indentation increment of the static indentation increment

Important parameter in the assessment of testing methods for resistance to permanent deformation is the measurement uncertainty. Due to the exploratory nature of the work associated with the use of dynamic indentation, it may give estimated values for the accuracy of the measurement method. For this purpose, the relative standard deviation was used RSD%. It was calculated as follow:

$$RSD\% = \frac{s}{x_{śr}} \times 100 \quad (1)$$

gdzie: *RSD%* – relative standard deviation, [%];
s – standard deviation;
$x_{śr}$ – mean value.

Result are shown in table 3.

Table 3. Relative standard deviation for samples tested

Sample	Mean [mm]		Standard deviation [mm]		Relative standard deviation RSD [%]	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
A	1.56	1.61	0.24	0.11	15.4	7.2
B	0.82	1.12	0.15	0.06	18.3	5.7
C	0.53	0.47	0.11	0.21	20.0	45.3
D	0.44	0.42	0.09	0.03	19.5	6.7
E	0.52	0.31	0.10	0.04	19.6	11.2
F	0.42	0.56	0.10	0.09	24.5	16.4
G	0.84	1.32	0.07	0.21	8.0	16.0
H	0.66	0.31	0.09	0.12	13.8	38.2
I	0.46	0.49	0.05	0.11	11.2	25.0
K	3.79	6.45	0.32	0.21	8.4	3.3
L	3.06	4.82	0.23	0.23	7.6	4.8
M	2.80	2.05	0.13	0.90	4.5	43.9
N	1.29	2.34	0.07	0.27	5.3	11.3
O	1.54	1.76	0.14	0.11	9.3	6.4
P	1.15	1.39	0.18	0.17	15.5	12.1
R	2.58	3.91	0.35	0.02	13.6	0.5
S	1.79	2.49	0.21	0.23	11.7	9.0
T	1.57	2.32	0.13	0.10	8.3	4.5

Presented data show greater accuracy of the dynamic method in the study of resistance to permanent deformation. In a few cases only, the coefficient of variation was greater than in the static method. The second research thread was to determine the effect of mastic asphalt composition on the sensitivity of the test method. The main assumption of this test was to check whether small differences in the penetration of the sample are caused by the way the sample was prepared (e.g., the way the aggregate was laid, the different degree of compaction) or it was only the effect of measurement inaccuracy. For this purpose, the one-way analysis of variance (ANOVA) test was used on 4 mixes with similar penetration values. Mixtures marked with letters: D, E, F and I were selected for comparison. Sample C was not included due to the high coefficient of variation. The static indentation values of these mixtures do not differ by more than 0.1 mm.

Table 4. Assessment of significance testing methods

Test method	SS	df	MS	F	p-value	Test F
Static	0.034953	3	0.011651	1.441	0.262	3.127
Dynamic	0.080233	3	0.026744	4.375	0.073	5.409

Symbols used in the table: SS – sum of squares; df – degree of freedom, MS – mean squared error; F – Fisher's statistic, p-value – the probability of obtaining test results at least as extreme as the results actually observed during the test, assuming that the null hypothesis is correct, Test F – critical F-value

Both analyzed methods do not statistically significantly differentiate the results of the penetration test at the confidence level $\alpha = 0.05$. Thus, it cannot be said unequivocally that it was the HMA composition that caused the difference in the indentation. It may as well be a measurement error or sample preparation method. Analyzis of the p-value draws attention to greater differentiation in the division of samples in the dynamic method (the p-value is slightly greater than 0,05), therefore it can be said that the dynamic method differentiates mixtures more than the static method. Also, the literature confirms the better usefulness of the dynamic method in the assessment of mastic asphalt, especially for mixtures with low penetration in the static test [3, 5]. It should be emphasized that the conclusions of the own research regarding the accuracy of the method ought to be confirmed by a larger number of samples tested. The static indentation test has already an established position in the Polish test methodology, which is why the requirements for mastic asphalt are confirmed in practice. Requirements for dynamic penetration adapted to Polish climatic conditions should be confirmed in practical applications. An example of foreign requirements that may be the starting point for creating Polish guidelines is presented in Table 5.

Table 5. Example foreign requirements for mastic asphalt tested dynamic method [5]

Category	Load due to		ET_{dyn} [mm]
	Traffic	Climate/Location	
1	Slowly rolling and standing heavy traffic (congestion range, slope/gradient)	Extremely warm summer, long direct insolation, mild winter	≤ 1.5
2	Rolling traffic with a high fraction of heavy traffi	Warm summer with direct insolation, mild winter	≤ 2.5
3	Rolling traffic with a low fraction of heavy traffic	Moderate temperatures, short insola-tion, cold winter, elevated location	≤ 5.0

3. Summary

Development of new research on the resistance of mastic asphalt mix is needed due to the insufficient methods currently used, especially for modern, hard mastic asphalt. The standardly used static penetration test does not sufficiently differentiate low penetration mixtures, only to a small extent enabling optimization of the MA composition. Modern test methods - penetration under dynamic load - give a greater opportunity for the most accurate selection of ingredients. The conducted own research confirmed that the presented method enables better differentiation of mixtures in terms of resistance to permanent deformations and HMA composition, than the static test.

4. Conclusions

- There is a need to find a better method for determining the resistance to permanent deformation of mastic asphalt. The current static penetration method used does not sufficiently differentiate mixtures in the penetration range of 1-3 mm.
- The dynamic method in mastic asphalt penetration testing is characterized by better testing precision.
- The dynamic method differentiates mixes to a greater extent, allowing the selection of the most optimal composition of mastic asphalt.

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