

## Regular Article

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# Assessment of resistance to permanent deformations of asphalt mixes of low air void content

<https://doi.org/10.1515/eng-2021-0120>

received December 30, 2020; accepted December 12, 2021

**Abstract:** This article presents the issue of resistance to permanent deformations of bridge pavements. In Europe, bridge asphalt pavement usually consists of the wearing course and the protective layer, which are paved on the waterproofing. Protective layers of bridge pavement are often constructed using low air void asphalt mixes. Such mixes are characterized by water-tightness, resistance to unfavorable environmental conditions, and enhanced fatigue life. Due to increased binder content, asphalt mixes for bridge pavement may display reduced resistance to permanent deformations. The article presents the test results of resistance to permanent deformations of asphalt mixes for bridge pavement. The study compares the rutting resistance for mixture use with low air void content. This specific kind of mixtures are dedicated to pavements on bridge deck. In this study, the resistance to permanent deformations was tested depending on the content of grit structure and air void content. Laboratory test results were compared for stone mastic asphalt and asphalt concrete, characterized by low air void content. Resistance to permanent deformations was assessed using the cyclic uniaxial compression (dynamic load creep) method. On the basis of analysis of the test results, it was shown that resistance of asphalt mixes to permanent deformations depends most of all on the type of mix designed and the air void content.

**Keywords:** permanent deformations, asphalt mixes, air void content, bridge pavement

## 1 Introduction

Asphalt mixes are generally used for the construction of all structural layers of road and airport pavement of varying designations, installed both on the ground and on the bridge decks [1–5]. In many cases, it is required that the pavement is characterized by proper tightness, determined by low content of air voids in the compacted asphalt layers. This applies, in particular, to pavements on bridge structures, which, due to operating reasons, should – among others – be resistant to water and de-icing agents, thus ensuring protection of the bridge decks. At the same time, the bridge pavement should be resistant to permanent deformations emerging under high operating temperatures, which is not easy to achieve in the case of low content of air voids in structural layers made of asphalt mixes.

The article presents the results of resistance to permanent deformations of asphalt mixes with low air void content. This type of mixtures are used for bridge pavement layers.

Based on the test results, it was found that it is possible to design waterproof asphalt mixtures with high resistance to permanent deformation.

## 2 Scope and objectives

Concrete bridge decks are very often used in civil engineering structures. This type of bridge decks are exposed to the damages related to possibility of water leaks through the pavement layers and its frosting and defrosting cycles. It can cause the corrosion of the deck. Therefore, it is necessary to take action to prevent or minimize the potential

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permeation of water and damp salt into the pavement structure.

The estimated period of use of concrete girder bridges is 80 years [6]. One of the prerequisites for ensuring such long life is to seal the bridge decks using high-quality asphalt layers [7–9]. Asphalt layers in bridge structures consist of the wearing course and the protective layer, laid on a waterproofing layer. Due to the operating conditions of the bridge pavement, these layers are made of asphalt mixes of semi-closed or closed structure. Typical materials of solution are asphalt concrete (AC) and stone mastic asphalt (SMA) [10–12]. Increased binder content, low air void content, and specific operating conditions of the bridge pavement may lead to permanent deformations in the form of ruts. On rigid bridge decks, stresses and compressive strains in the bridge pavement caused by vehicle wheel loads are dominant, and the durability of the pavement depends largely on resistance to permanent deformations [13–15]. The test results [15–20] have confirmed that stresses and strains in the bridge pavement layers achieve unfavorable values, higher than vertical stresses and strains in the pavement layers on the ground. High compressive strains may result in excessive viscoplastic strains of asphalt layers under high operating temperatures. The value of strain depends on the stiffness modulus, which, on the other hand, is determined by temperature, load frequency, and load time and value. High compressive strains are particularly dangerous in the summer heat period, when the pavement temperature reaches 70°C (at the air temperature of 35°C) [10,21,22].

A traditionally safe solution for the bridge pavement construction consists of two layers of thickness of around 4 cm each. A common solution is to use a wearing course with a thickness reduced to 2 cm. In such solutions, mixtures with discontinuous grain size distribution are used. Application of thick bridge pavement is not beneficial from the designer point of view, aiming at reducing the bridge structure deadweight. Application of thin bridge pavement is acceptable, if the structural layers are built of a material showing increased capacity for stress and strain decay under low temperature and proper rigidity under high temperature.

WT-2 Technical Requirements [23] for asphalt mixes are used for the protective layer, they recommend using only mastic asphalt, which, despite its high tightness, may not be resistant to deformations.

Durable and safe bridge pavement requires the proper selection of materials, an appropriate technology, and the highest quality of performance. This can be achieved, among other things, by using standard technologies, such

as SMA with modified binders and increased binder content [24], as well as other new materials and technological solutions, such as mixes containing binders modified with polymers and addition of crumb rubber [25].

Resistance of asphalt mixes to permanent deformations under high surface operating temperatures can be characterized by a number of parameters, which allow for a complex and precise description of material properties. The most popular method of evaluation of resistance to permanent deformations is examination of rut depth and increase in a single layer of the asphalt mix under a cyclical load at the temperature of 60°C [1,9,14,26]. Hardness of mastic asphalt is evaluated using the static or dynamic punch penetration method. Resistance of asphalt mixes to permanent deformations is also frequently assessed using the compressive creep test at the elevated temperature of 40–60°C. In this method, also known as the cyclic uniaxial compression, cylindrical samples are subjected to a vertical compressive load, which may be static or cyclic. Most often, such tests are conducted under laboratory conditions at the uniaxial load without a lateral limit [13,26,27]. The compressive creep method is effective in determining the behavior of asphalt mixes with high mastic asphalt content and low air void content under cyclic loads. Therefore, this method for evaluation of resistance to permanent deformation has been applied in the research project described in this article.

### 3 Materials and methods

The tests of resistance to permanent deformation were conducted for two types of mineral mixes and six types of asphalt mixes including AC (AC 11) and SMA (SMA 11). Mixes with suffix-A (AC-A and SMA-A) have 5% bitumen content, mixes with suffix-B (AC-B and SMA-B) have 6% bitumen content, and mixes with suffix-C (AC-C and SMA-C) have 7% bitumen content. The grain size distribution designed in accordance with the requirements of WT-2 [23] is presented in Figure 1.

The SMA and AC mineral mixes contained only crushed-stone aggregates are presented in Table 1. The SMA mixtures were prepared with the addition of cellulose fibers.

The content of polymer-modified bitumen PMB 45/80-55 was the variable examined in composition of the asphalt mixes. The bitumen content was in the range of 5–7% (Table 2). The calculated air void contents for all asphalt mixes are presented in Table 3. PMB 45/80-55 is a typical bitumen for these applications recommended in

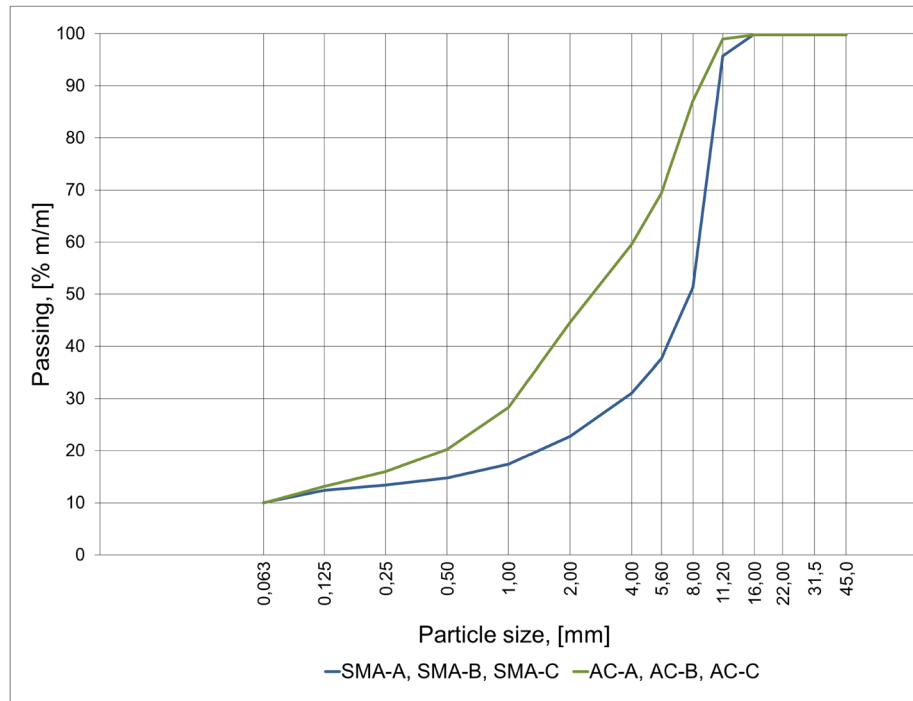


Figure 1: SMA and AC mineral mix grain size distribution.

Table 1: Composition of mineral mixes

Material/mixture grading type	Mineral mixture (%m/m)	
	SMA-A, SMA-B, SMA-C	AC-A, AC-B, AC-C
Mineral filler	9.9	5.5
Basalt aggregate 0.063/2	14.0	44.0
Basalt aggregate 2/5	11.8	17.0
Basalt aggregate 5/8	11.0	22.3
Basalt aggregate 8/11	53.3	11.2

Table 3: Air void content in asphalt mixes

	Mixture type					
	SMA-A	SMA-B	SMA-C	AC-A	AC-B	AC-C
Percentage content of air voids (%v/v)	3.6	1.6	1.3	3.7	1.8	1.5

Poland. The air void content was calculated from density and bulk density according to PN-EN 12697-8.

Asphalt mixes were compacted using a gyratory compactor in accordance with PN-EN 12697-31 in cylindrical steel molds of diameter of 150 mm and height of 70 mm. For all mixes the gyratory number was 60 and the compaction temperature was 145°C. Five samples were made for each type of mixes. The low air void content was achieved by adjusting asphalt content. This allowed for obtaining of samples of asphalt mixes with a developed mastic structure and high binder content, typical for highly leak-tight mixes, which were subjected to tests of resistance to permanent deformations.

In order to evaluate resistance of asphalt mixes SMA and AC to permanent deformations, the test plan

included the cyclic uniaxial compression (dynamic load creep) method according to PN-EN 12697-25, which, according to ref. [13], effectively characterizes the high-temperature properties of mixes with reduced air void content.

Testing of resistance of asphalt mixes to permanent deformations using the cyclic uniaxial compression method consists of acting on the sample repeatedly many times with a stress load of the same value. The test consists of 3,600 load cycles. The test temperature was 50°C. The test was conducted on five samples of each type of the asphalt mixture. The samples were cylinder shaped with a diameter of 150 mm and a height of 70 mm. The loading pressure was 100 kPa. The deformation was measured using vertical displacement sensors. The test result is the final sample deformation and the proportional curve of the deformation graph.

**Table 2:** Composition of asphalt mixes

Percentage content of an ingredient (%m/m)	Mixture type					
	SMA-A	SMA-B	SMA-C	AC-A	AC-B	AC-C
Binder PMB 45/80-55	5.0	6.0	7.0	5.0	6.0	7.0
Mineral filler	9.4	9.3	9.2	5.2	5.2	5.1
Basalt aggregate 0.063/2	13.3	13.2	13.0	41.8	41.4	40.9
Basalt aggregate 2/5	11.2	11.1	11.0	16.2	16.0	15.8
Basalt aggregate 5/8	10.5	10.3	10.2	21.2	21.0	20.7
Basalt aggregate 8/11	50.6	50.1	49.6	10.6	10.5	10.4

## 4 Results and discussion

Figure 2 presents the results of tests of resistance to permanent deformation using the cyclic uniaxial compression of asphalt SMA mixes with varying air void contents.

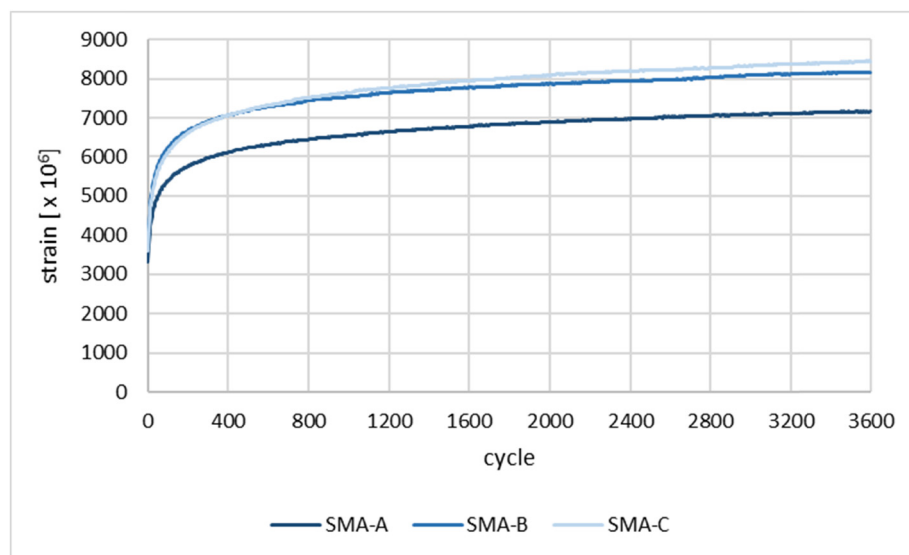
On the basis of results of tests of SMA mixes presented in Figure 2, it can be stated that all of the SMAs analyzed are characterized by high resistance to permanent deformation. Evaluation criterion was established on the basis of preliminary evaluation and comparison of the results of the cyclic compression test and rutting test. In the initial test phase, there is a substantial increase in vertical strain, after which strain stabilization takes place. The graph inclination is similar for the mix of the air void content of 3.6 and 1.3%, which suggests domination of the elastic part in these composite materials. The reason for the high resistance to permanent deformation of SMA mix is most probably the appropriately selected load-bearing chipboard with discontinuous graining. Figure 3

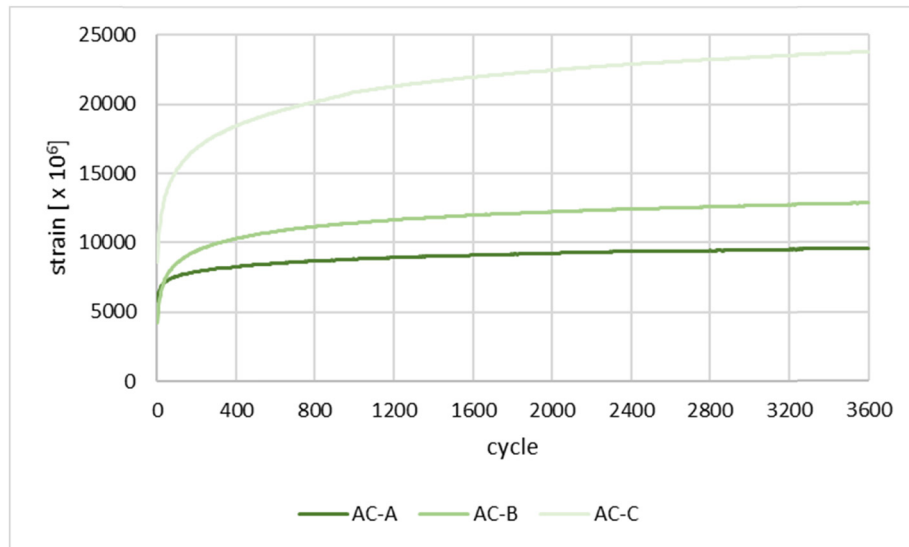
presents the permanent deformation resistance test results for AC with varying air void contents.

On the basis of test results of AC mixes presented in Figure 3, it should be stated that all of the ACs analyzed are characterized by lower resistance to permanent deformation in comparison with SMA mixes. Like in the case of SMAs, in the early phase of rutting, there is a substantial increase in vertical strain, after which the strain begins to stabilize. Inclination of the graph for the mix with the air void content of 1.5% is greater in comparison of the mix with the air void content of 3.7%, which indicates dominance of the viscous part as the binder content in the composite material increases. AC is more sensitive to change in the air void content in comparison with SMA.

Figure 4 presents a comparison of resistance to permanent deformation of SMA (SMA-A) and AC (AC-A with the highest air void content).

The results of tests of resistance of both asphalt mixes with the highest air void content to permanent

**Figure 2:** Permanent deformation of SMA with varying air void contents.



**Figure 3:** Permanent deformation of AC with varying air void contents.

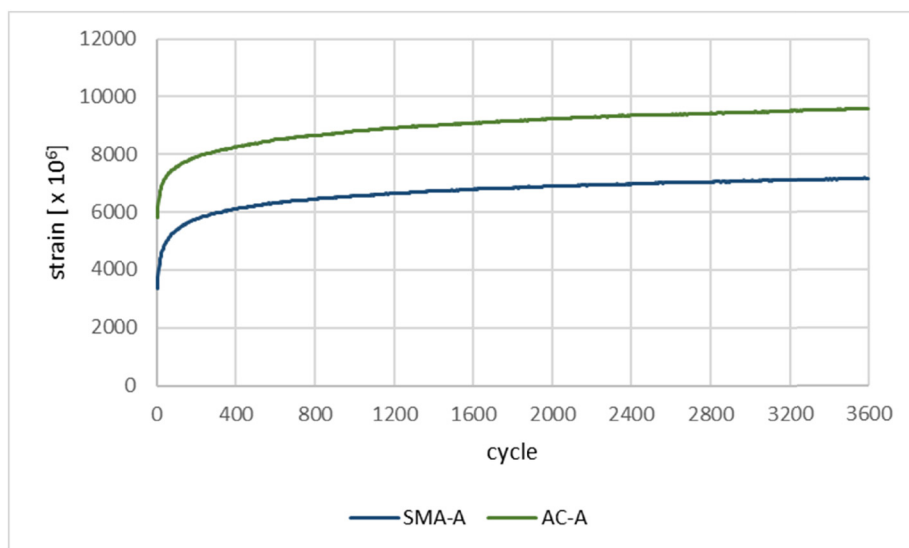
deformation indicate their similar work in the structure of the bridge pavement. The strain increase (graph inclination) is similar for both mixes. However, AC mixes are characterized by more substantial deformations, which may lead to their reduced resistance to permanent deformation in comparison with SMA. This is due to the continuous grain size distribution of the aggregate containing a high crushed sand fraction.

Figure 5 presents a comparison of resistance to permanent deformation of SMA (SMA-C) and AC (AC-C) with the lowest air void content.

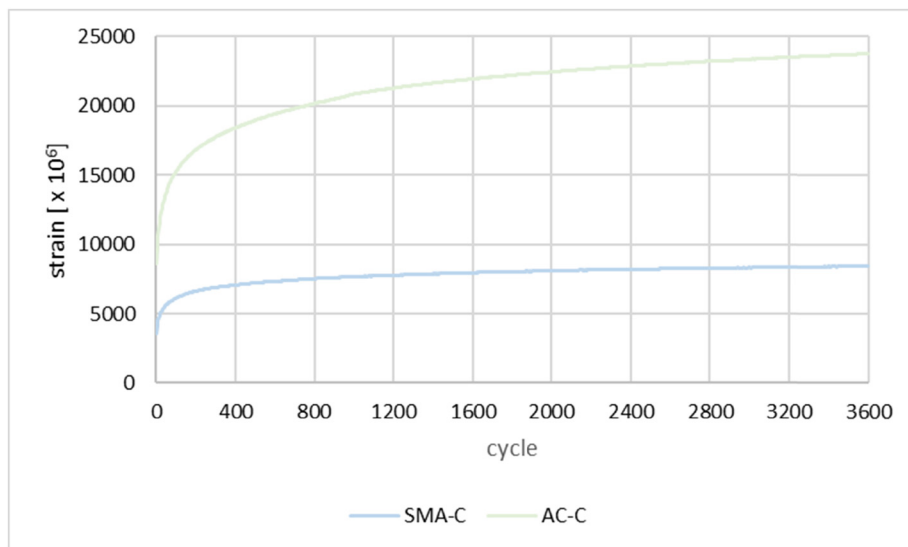
The results of deformation tests of both mixes vary substantially (Figure 5). AC, at the air void content of

1.5%, should be considered to be a leak-tight mix. However, the substantial increase in strain of the AC-C mix suggests that the mix is “flowing” and it will not perform its role properly in the bridge pavement structure. The behavior of this material is viscous within a greater range in comparison with the SMA mix. In the case of the SMA-C mix, the increase in deformation level remains stable, and the stress applied and the response in the form of deformations are approximately constant. The dominant part of this composite material is elastic.

Figure 6 presents the results with error bars and standard deviations of accumulated final deformation obtained in the dynamic load creep test of SMA and AC mixes with



**Figure 4:** A comparison of permanent deformation of SMA (SMA-A) and AC (AC-A) with the standard air void content.



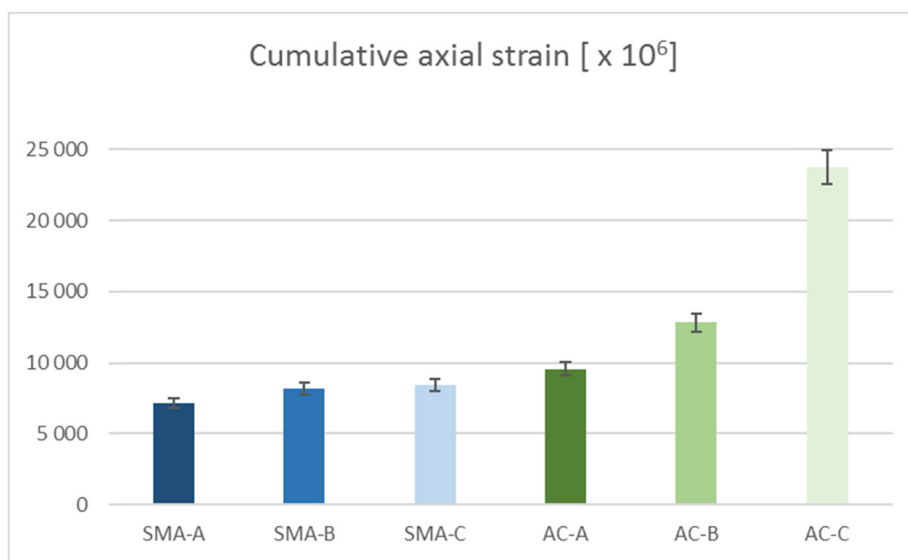
**Figure 5:** A comparison of permanent deformation of SMA (SMA-C) and AC (AC-C) characterized by low air void content.

varying air void contents, conducted using the cyclic uni-axial compression method. Figure 7 presents the results with error bars and standard deviations of inclination of the deformation curve which characterize the pace of increase of deformation for individual asphalt mixes.

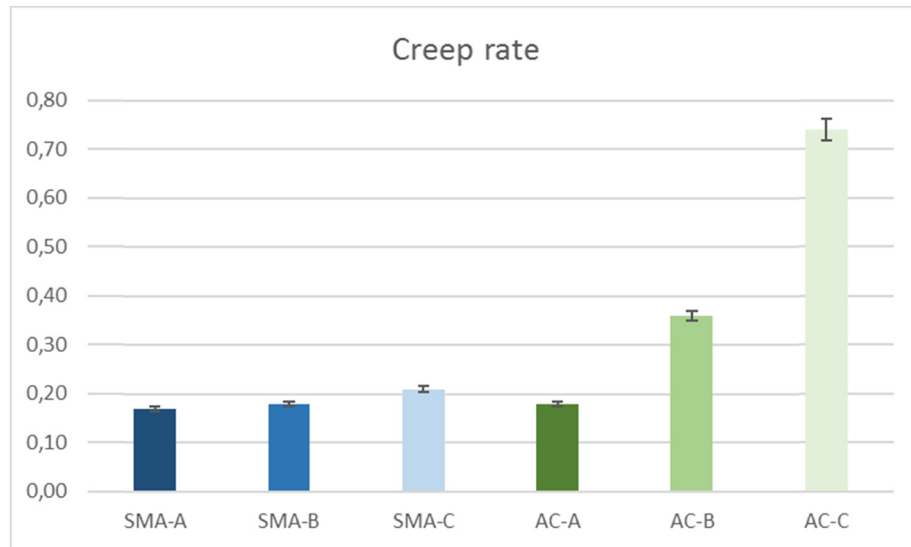
The results of creep tests, presented in Figures 6 and 7 (total final deformation and proportional inclination of the deformation graph), of SMA and AC indicate that there is similarity between the mixes compared only in terms of the highest air void content. As the leak-tightness of mixes increases, the creep test results vary substantially:

SMA retains stability of results, while in the case of AC, there is a substantial increase in creep, which proves the sensitivity of this mix to the change in the air void content.

On the basis of the statistical analysis conducted, it was found that susceptibility to permanent deformation depends largely upon the grain size distribution of the asphalt mixture. Correlation and variance analysis was performed. SMA mixes characterized by a developed mastic structure do not show a substantially increased susceptibility to deformation increase as the air void content decreases. For AC mixes with a continuous grain size



**Figure 6:** A comparison of total final permanent deformation for SMA (SMA-A, SMA-B, SMA-C) and AC (AC-A, AC-B, AC-C) of varying air void contents.



**Figure 7:** A comparison of permanent deformation (creep) curve values for SMA (SMA-A, SMA-B, SMA-C) and AC (AC-A, AC-B, AC-C) of varying air void contents.

distribution, resistance to permanent deformation deteriorates substantially as the air void content decreases. Moreover, a strong correlation (Pearson correlation coefficient  $r = 0.68$ ) was found between the air void content and resistance of asphalt mixes to permanent deformations obtained in the cyclic uniaxial compression test.

The mechanism of reducing the resistance to permanent deformation as a result of increasing the binder content of SMA and AC mixtures is different. The SMA mixture is characterized by a discontinuous grading curve and a high content of the grit fraction. The grit skeleton obtained by interlocking grains of coarse aggregate is designed to transfer loads from vehicles. Reducing the air void content in this type of mixes by increasing the binder content does not significantly reduce the resistance to permanent deformation. The binder fills the free spaces between the grains of the grit skeleton and does not change the grit skeleton structure. The AC mixture has a continuous grading curve and increasing the binder content significantly reduces the contact between the grains. As a result, the resistance to permanent deformation is reduced.

## 5 Conclusion

Bridge asphalt mixes are designed differently from those to be used on the ground surface. The dominant features of these mixes are leak-tightness and resistance to permanent deformation. Increased binder (mastic) content and specific operating conditions of the bridge pavement

may lead to permanent deformations in the form of ruts. Various asphalt mixes can be used for construction of bridge pavement; in practice, these often include AC and SMA with the properly developed mastic structure. The study compares the rutting resistance of mixture use with low air void content. This specific kind of mixtures are dedicated to pavements on bridge deck. In this study, the resistance to permanent deformation was tested depending on the content of grit structure and air void content. Tests of resistance to permanent deformations using the cyclic uniaxial compression of asphalt mixes characterized by varying air void contents showed that deformations increase as does the leak-tightness of the asphalt composite materials. Mixes with low air void content are thus more susceptible to permanent deformations under load caused by traffic. In the first phase of the test, there is a quick increase in strain, after which the strain begins to stabilize. In the creep test of asphalt mixes, their elastic or viscous characteristics are revealed to a lesser or greater extent.

As a summary, it should be stated that

- SMA is characterized by high resistance to permanent deformations within the range of air void content from 1.3 to 3.6%, which indicates a favorable domination of the elastic part in composite materials of this kind under high operating temperatures,
- AC with the air void content from 1.5 to 3.7% shows deteriorated resistance to permanent deformation (higher creep), particularly in the case of the lower air void content, which suggests domination of the viscous part in composite materials of this kind under high operating temperatures,

- due to the possibility of designing a more developed mastic structure, resistant to permanent deformations at the low air void content, SMA should be considered to be the mixture, which will ensure better work of the bridge pavement structure layers in comparison with AC.

**Acknowledgments:** The tests were conducted within the framework of preparation of the PhD thesis of MSc Eng Piotr Pokorski, as well as in the course of performance of statutory works at the Faculty of Civil Engineering of the Warsaw University of Technology.

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