Correlation Between Asphalt Concrete Strength, Amount of Bitumen and Asphalt Mix Batching Modes

Bashkarev Albert Y. a, *, Kudravtseva Natalia N. a, Rajczyk Jaroslaw b

a St. Petersburg State Polytechnical University, Politekhnicheskaya, 29, Saint-Petersburg, 195251, Russia
b Poland, 42-201 Częstochowa, Polska, ul. J. H. Dąbrowskiego 69, Politechnika Częstochowska

Abstract

The article introduces the results of the experimental research of the effect of confinement and steel fiber reinforcement on the strength and strain of the compressed elements of high-modified as well as high-strength SFRC. Analytical expressions to describe the strength and strain of elements with confinement reinforcement under axial compression have been proposed. The results of the research of the effect of concrete age and temperatures elevated up to 150°C on the strength and strain of high-strength SFRC have been introduced.

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Keywords: High-strength concrete, confinement reinforcement, steel fiber reinforced concrete (SFRC), short-term heating, elevated temperatures, axial compression, strain, strength

1. Introduction

In Asphalt concrete is a compound material wherein three mineral components: gravel, quartz sand and mineral powder, are mixed into a single composite using bitumen. For many years there have been a large number of publications with the results of scientific research and technical tests examining the correlation between the strength of asphalt concrete, its components properties and quantitative proportions [1–4].

For recent years a particular attention has been paid to bitumen consisting of several organic macromolecular
components [5–7]. Its adhesive, physical and mechanical properties predetermine the bearing strength of the composed composite compound in a variety of climatic conditions.

Presently there are numerous recommendations to improve bitumen properties using different polymer additives, mainly related to thermoplastics [8–10]. So-called modified bitumen has appeared.

There are some studies with the attempts to explain the nature of their impact on bitumen properties [11–12]. However, there have been no scientifically reasoned explanations so far. Therefore, a search of optimal technological modes while using polymer additives and detecting the quantity has no theoretical basis and is effected by the trial and error method.

It is fairly considered that gravel strength in the asphalt concrete is of the same importance as bitumen adhesive properties. As a result of gravel destruction there are the surfaces within the gravel not bonded with bitumen. In fact these are macro defects in the composite mass. Therefore, it is crucial to take seriously the opinion of experts who recommend producing and using widely the gravel of cubical shape that ensures less gravel destruction. Special technologies and equipment to produce the gravel of this shape have been designed [13]. The problem is in legal requirements for its use in the road construction, i.e., in improving the standards.

2. Correlation between asphalt concrete strength, amount of bitumen and asphalt mix batching modes

The role of quartz sand is clear. It fills the spaces between the gravel, reducing its mobility and redistributing the load between the fractions.

Until recently scientific publications have provided little information on the role of mineral powder in the asphalt concrete. Obviously, it is assumed that, firstly, it reduces particles mobility of quartz sand, secondly, it increases bitumen viscosity in the asphalt concrete reducing its mobility at higher temperatures. However, the selection of materials used in the bitumen-concrete mix as mineral powder has not been justified. This can be quartz dust, different ashes etc. What matters is minimum dispersion.

The present study brings forth another concept of mineral powder and its amount in the composition.

Several tests with BD 60/90 bitumen and granite have been conducted by the procedure as follows.

A set of rectangular specimens (dimensions: 20*30*40) were made of granite. The specimens were fastened by bitumen at 140OC by the scheme shown in Fig. 1.

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Fig.1. Granite specimens fastened by bitumen and scheme of their destruction. 1 - Granite specimens, 2 – Bitumen.
Heating and cooling modes were kept equal for each specimen. The thickness of the connecting bitumen layer was the only value to change. For this purpose narrow foil strips of different thickness were laid in a layer of molten bitumen, after that the specimens were compressed with a clamp and hereby were cooled to the normal temperature. Then, within 48 – 50 hours the specimens were destroyed by shear stresses (see Fig.1). The results of the tests are presented in Fig. 2 as a diagram, where each point is an average of five tests.

The horizontal dashed line in the same figure demonstrates shear strength of the same BD 60/90 bitumen tested at 20OC by the procedure shown in Fig. 3. Shear stresses in the bitumen = \( S/\pi D \delta \) layer were calculated by the formula as follows.

The obtained results of the fastened specimens demonstrate that bitumen strength in the friction zone is significantly higher than in a simple massif.

The similar effect in the adhesive fastening of polyamide with steel has been detected by Vettegren V.I [14, 15]. Examining the condition of the polyamide coat on the metal base by strained infrared spectrometry, he revealed that polymer molecules in the immediate area of adhesion were compressed to match stresses of a few hundred MPa.
These stresses are depleted over the distance from the metal but at the distance of 200 microns they still exist.

Vettegren V.I. explained this effect by the appearance of coordination bonds between the two materials, more specifically, by penetration of iron ions in the polymer and their interaction with nitrogen atoms that are presented in the molecular structure of the polyamide. As a result, during specimen adhesive strength tests cohesive failure of compound constantly occurred.

A similar pattern of destruction has been detected in the present study when testing granite specimens have been fastened by bitumen. But there has been no explanation of this effect so far. However, it is seen that with the same cohesive type of destruction the compound strength increases with decreasing the bitumen layer thickness. This effect has been noticed throughout the entire range of the tested bitumen layer thicknesses.

It is important to consider that unlike polished granite specimens used in the bitumen-concrete mix, gravel has irregular shape and rough surface. Applied quartz sand with the particles covered by bitumen decreases a negative impact of gravel irregular shape. But quartz sand with a relatively large size of its particles cannot fill and level surface roughness of used gravel. This role is performed by mineral powder that has higher dispersion.

The pinout scheme of mineral components in the bitumen-concrete mix through their bituminous coating is shown in Fig. 4.

To ensure a maximum strength of asphalt concrete resulting from compressing and cooling, it is required to provide a maximum actual pinout area of three mineral fractions with a minimum thickness of the intermediate bitumen layer. It is preferred for each particle, being in the mixer, to have a coating not exceeding 200-200 microns. A bitumen excess during the mix compressing process will prevent the particles from approaching, which eliminates the potential for achieving the maximum strength and road pavement stability improvement under shear loads.

Even at an optimum bitumen layer thickness it is possible to increase its strength by the proper selection of temperature and time modes during the process of bitumen-concrete mix batching, transportation and laying in the road pavement. This has been proved by another test conducted with specimens shown in Fig. 1.

The specimens were fastened at the same temperature equal to 140°C, but after fastening they were held at the same temperature for different periods of time. After that they were cooled to the normal temperature and tested for strength. Strength test results are shown in Fig. 5.
The obtained correlation is confirmed by numerous tests. Using the thermofluctuational strength theory, the authors have developed a mathematical model of bitumen adhesive strength change at different temperatures [16].

Recently many bitumen concrete plants have been equipped with capacious thermostats to store the prepared bitumen-concrete mix. This provides them with an option to evenly load the operating equipment and eliminates transport downtime. However, it is possible to use the thermal conditioning process not only to store the bitumen-concrete mix but to improve its quality by applying test results presented in Fig. 5.

It is known that only a portion of the radicals formed as a result of bitumen thermal decomposition is realized in the establishment of adhesive bonds with other components of bitumen-concrete mix [17-18]. Other radicals interact with each other and create three-dimensional structures, which makes the bitumen layer less flexible. Clearly, this must affect the deformability of the entire asphalt concrete, i.e. road carpet. The harder the bitumen layer in the composite is, the less the deformability and the slower the formation of a road track will be.

The authors of this paper explored the dependence of shear deformation on the magnitude of shear stress by testing adhesive strength. The speed of composite deformation was constant for all samples - 0,01 mm/s. For the conditional shear deformation $G_y$ in $\frac{\text{MPa}}{\text{m}^2}$, modulus behavior graph for the samples with the same thermostatting modes as before see Fig. 6.
The results show that thermostatting changes not only the strength of bitumen-granite composite, but also its deformability (although to a lesser degree). The composite strength increased 4 times, and the conditional deformation modulus increased about twice.

In summer, asphalt-concrete road carpets work at high temperatures. It is the time when the intensive formation of a road track takes place. The composite's ability to withstand load when heated turns out to be decisive in the evaluation of its quality [19-20]. This paper features a comparative test of non-thermostatted granite-bitumen adhesive bonds and bonds thermostatted at 140 °C for 25÷28 hours. The tests were carried out in the temperature range of +5 ÷ +40 °C. The results of the adhesive strength test are presented in Fig. 7, where curve 1 shows changes in the strength of thermostatted samples, while curve 2 shows changes in the strength of non-thermostatted samples.

Fig. 7. Comparison of adhesive strength test results for samples before and after thermostatting.

It can be seen that with the common asphalt concrete at 40 °C (in summer, road carpet heats even more) an intensive road track formation process is inevitable. Thermostatting is a cost-effective technology change that can substantially reduce this negative phenomenon.

Conclusions

The conducted studies have shown that the increase in the strength of asphaltic concrete pavement can further be achieved, in addition to known coating methods, by improving the adhesion of bitumen by:

- setting the optimal temperature and time technological modes of bitumen-concrete mix batching
- reducing the amount of bitumen in the bitumen-concrete mix to the level which ensures covering each mineral particle with a layer not exceeding 100 microns

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