Automatic installation "UONDA 14-20" to determine deformation, stress and fracture of materials

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ABSTRACT

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We have developed automatic installation UONDA 14-20, which allows to determine in an automatic mode indicator on 15 properties of composite materi-als (asphalt concrete, cement concrete, mortar, etc.) at tempera-tures range from -70 to +70 ° C for three test specimens schemes.
Scheme I – while cooling, heating or maintaining isothermal restra-ined by corners sample and determine the following parameters: 1) struc-tural shrinkage stress σs, thermal shrinkage stresses σt or shared structural thermal stresses σst; 2) temperature of the cracking of the structural and/or thermal shrinkage stress Tc and the ultimate strength of these stresses Rt, 3) period of thermal stress rela-xation mt..
Scheme II - by mechanical uniaxial tension and determine the follo-wing parameters 4) stress in uniaxial tension σp and tensile strength Rp; 5) the strain in uniaxial tension ξp; 6) a module of elasticity E; 7) a compressive frac-ture A.
Scheme III - while cooling or heating of the sample and lying freely define the following parameters: 8) coefficient of linear thermal expan-sion of λ; 9) structural transition temperature (Tc glass transition , fluidity Tm , etc.); 10) linear structural shrinkage ξ y;
The installation consists of a test machine, refrigerating or an electric boxes, remote measurement and recording temperature efforts and deformations. Eight samples were tested, 30 cm long with a cross section of 5 by 5 cm at cooling - heating the sample from 0,53 °C/min or less and at deformation rates of the sample from 0.034 till 49 mm/min for mechanical testing .
Automatic installation of UONDA 14-20 allows to test of samples of ma-terials as in the initial condition and after aging. Moreover, the aging of the sam-ples can be made at certain modes directly in a thermostatic camera installation and samples aged under different conditions, including operational. Installing UONDA 14-20 favorably determined by number of indicators, accuracy tests, ease in construction and maintenance of the well-known machine CRT-APTTC, used for study the crack on asphalt samples by the method of AASHTO TP10 and EN12697-46.

Keywords: Asphalt

1. INTRODUCTION.

The materials employed in road surfaces are exposed to tensile stress. There are the following types of stresses in pavements:
-tensile thermal stresses due to the inability of free movement of coatings on cooling (σ_t);
- tensile stress during braking or acceleration of vehicles(σ_v);
- periodic bending stresses under the action of transport (σ_b);
- stress caused by lifting of underlying subgrade when it freezes (σ_s);
These stresses increase during aging of the coating material. There are many methods and devices to determine the fracture toughness properties of materials. They are: strength methods (compressive strength, tensile strength, and bending strength), rheologic methods, fatigue methods and others. However, considering the diagram of material stress in the road surface it should be noted that at low temperatures the tensile stresses are determined by elastic modulus and coefficient of linear thermal expansion of the material. This is not included in the tests according to the above mentioned methods.
Appeared in recent years, instruments and techniques presented in the AASHTO TP 10-93 and EN 12697-96, allow to approach an objective assessment of the crack resistance of asphalt-concrete coatings when samples are tested at two circuits. Previously developed UONDA 14-20 automatic unit allows to determine stresses, deformations and temperature of materials cracking at three test circuits of samples to produce exhaustive characteristics of crack resistance of asphalt concrete, cement concrete, mortar and other materials. It also allows to create these materials with the required levels of quality.

2. OVERVIEW OF THE STATE OF THE ART.

When there is a joint effect (transportation, weather, aging) tensile stress (σ_{ts}) occurs in road surfaces. When equal to tensile strength (R_p) σ_{ts} value is attained, cracking of the coating occurs. In accordance with GOST 9128-2009 fracture toughness abilities of asphalt concrete are the compressive strength at 0 °C and a tensile strength during the rupture at 0 °C and strain rate of 50 mm / min, which are determined in accordance with GOST 12801-98. In accordance with GOST 9128-2009 compressive strength h in the asphalt concrete at 0 °C should not be above a certain limit, and tensile strength at rupture should not be lower or higher than certain limits. Imperfection and subjectivity of standard score of crack resistance forced the researchers to look for more objective characteristics of crack resistance of asphalt.
A number of methods and devices for determining fracture toughness of asphalt concrete were suggested. There are methods for the determination of heat resistance, density, fracture toughness, sonic modulus [1,2]. Gubatch LS. and Ponomariova S.G. in their work [3] proposed to determine a brittleness temperature of asphalt concrete using temperature at which the dependence of the "stress - time " defined in the test samples at different low temperatures becomes straightline. Another invention by the same authors [4] proposed to determine crack resistance of bituminous materials using the temperature at which the shear modulus of samples reaches a maximum value and has not relaxation character. Patent [5] suggests to characterize crack resistance of materials by the value of the dynamic hardening getting from testing of samples at various loading rates and to determine the critical length of the main crack.
According to [6] in structures working under conditions of inability to move, while cooling with ΔT in a linear state of stress, there are thermal stresses (σ_t) which are equal to:

$$\sigma_t = E(\lambda_n - \lambda_o)\Delta T, \qquad (1)$$

where E and λ_n are elastic modulus and the coefficient of linear thermal expansion of the coating material; λ_o - the coefficient of linear thermal expansion of the base material.
Development of cement concrete or asphalt concrete for pavement with the lowest cracking temperature (T_c) is possible after determining the impact of constituent materials on indicators of cracking temperature by the equation (1), the elastic modulus, the coefficient of linear thermal expansion of the coating material and a base with temperature ΔT from T_1 to T_c, where T_1 is the temperature of the appearance of temperature stresses during cooling of the sample fixed at both ends.
It is more efficient to characterize the crack resistance of coatings using cracking temperature, because to determine it is much easier than any other complex rheological characteristics. Besides, T_c , found during operating cooling rates of asphalt concrete sample corrected due to the influence of operational factors[7] on it, including those caused by aging of asphalt concrete, can be taken as calculated characteristic of asphalt concrete for use in specific conditions.
A device for determining of internal stress and crack resistance of materials represents form in which the sample is [8.9]. Form is bounded with grippers and the side plates. The grippers are made of a material, which has higher linear thermal expansion coefficient (LTEC) than the material of side plates has and their temperature dependences are proportional. Length of grippers - l , their LTEC - λ, a side plate length - l_1, its LTEC - λ_1 are related as $2l\lambda=l_1\lambda_1$.
Thus, thermal expansion (compression) of the grippers captures totally compensates expansion (compression) of the side plates. This provides length persistence of a sample constrained by the grippers, when it is cooled or heated, ease andaccuracy of determining of internal stresses and cracking temperature of thesample.
However, these devices do not detect other characteristics, such as: elastic modulus, linear thermal expansion coefficients, tensile strength that affect σ_t and T_c of a material, knowledge of which enables targeted selection of compositions and processing solutions of production of materials with the required fracture toughness.

The study of the behavior of materials under mechanical, thermal and structural-shrinkage stresses or deformation of a sample constrained at both ends is difficult because of a lack of perfect test facilities. A device developed by Raspopov I.M. was used for determining of thermal stresses and cracking temperature during cooling of asphalt concrete samples constrained at both ends and their linear thermal expansion coefficients [10]. However, the high sensitivity and instability of the optical fixing of deformation , as well as manual loading did not contribute to the spread of the plant.

3. "UONDA 14-20" AUTOMATIC UNIT DESCRIPTION.

In the 70s of the last century in the Bashkir Research and Development Establishment of Petroleum Processing an automatic unit was developed. The unit made it possible to test materials at temperatures from +70 to -70 ° C at 3 circuits: I - when cooling or heating - at thermal stresses of a sample constrained at both ends; II - at mechanical uniaxial stress; III - when cooling or heating - at temperature deformation of a floating sample.
The unit consists of following items: a testing machine, refrigeration and electric heating systems, temperature measurement remote unit , loadings and deformations.
The frame 1 (Figure 1) of the testing machine is a rectangular frame welded of channel bar. The draw rod 2 is pinned to one of the arms of the frame and is connected to the gripper of the sample. The second gripper of the sample is connected to the drive with the rod, joint, dynamometer 12, joint and the lead screw 13 passing through the load nut 14 set in an opposite arm of the frame. Electric drive consisting of a gear 17, the electromagnetic clutch 18 and the motor-variator MVR 1-8SH 19. When switched off the path speed of the lead screw is 4,7-4,9 mm/min, added speed limit of screw

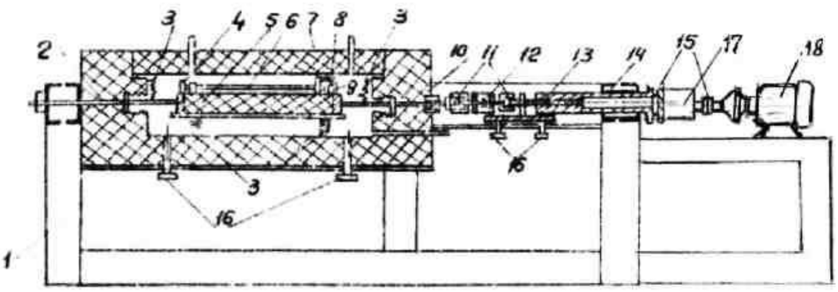


Figure 1: UONDA 14-20 automatic unit for determining deformations, stresses and cracking of materials. 1 -frame, 2-rod, 3-spring suspension,4-adjusting screw, 5 -specimen, 6-invar or quartz rod, 7-support, 8-contacts, 9- tumbler, 10- heat insulation, 11- joints, 12 -dynamometer,13- lead screw, 14- load nut, 15 -clutch, 16- adjustment screws, 17-gear,18- motor-variator MVR1-8SH

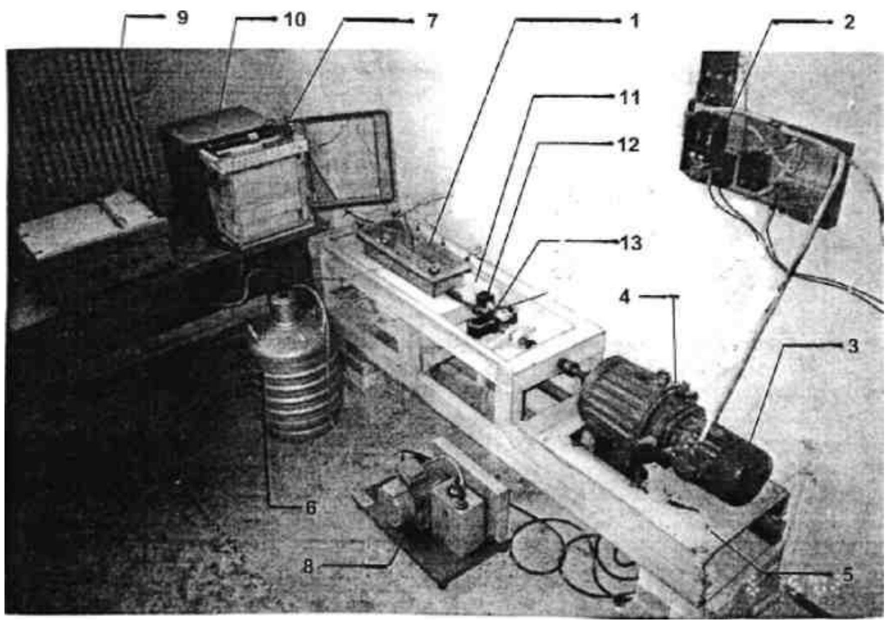


Figure 2: UONDA 14-20 automatic unit . 1 -thermostatically controlled chamber, 2-control panel; 3-motorized variator,4-gear; 5 - frame; 6 - Dewar bottle of liquid nitrogen,7-speed dial changes in temperature,8-compressor with pressure gauge,9-PDS-021M - x/y recorder,10-single point potentiometer KSP-4, 11 - heat insulation,12 motion-sensor of dynamometer, 13 – dynamometer

limit of screw travel with set in gear is 0,034-0,35 mm / min. Thus the speed of lead screw travel is located within the 4 decades that gives the possibility of dynamically performing uniaxial tension test and determining of complex characte-teristics of materials and phase angle.
Force-measuring machine is a spring dynamometer and its deformations are linearly related to the tension force Elect-ric signal is fed to one of the PDS-021M - x/y recorder coordinates. Deformation sensor of dynamometer is a conden-ser and its plates are secured by fluoroplastic sleeve inside the ellipse of dynamometer.
To measure the deformation of the sample during the test in accordance with circuit II or III capacitive linear encoder i used. Its operating principle is similar to the sensor installed on a dynamometer.
When tested specimens constrained at both ends under the loading circuit I, sensor of length consistency is used . Its operating principle is to apply a signal to the drive at sample size fluctuation. The sensor consists of quartz or invar rod 6 which is fixed to an support in the collet mechanism of the adjusting screw 4. The other end of the rod passes through a hole in the support 7 and bumps into the tumbler 9 of the contact device. The support 7 is designed as a loop, inside of which two platinum contacts 8 are arranged. Located between contacts tumbler 9 closes the circuit at the time of size fluctuation of the sample 5 when it is subjected to compression or tension.
For temperature control, cooling and heating of the sample in the developed automatic unit a system, in which the coo-lant is liquid nitrogen and a heater is hot air, has been adopted. Cooling-heating speed of specimens is carried out in ac-cordance with a program: from 15° C / hour or less.
Remote of measuring temperature, forces and deformations is formed as a separate panel, with an actuator and measu-ring device on it. PC makes it possible to control the test, store test results, cast them in the form of graphs and print them out.
During the test under the circuit I - at cooling , heating or isothermic holding of a sample constrained at both ends - the plant provides the following indicators:
1) structural shrinkage stress ($Ϭ_s$), thermal shrinkage stress ($Ϭ_t$)or structural- thermal stresses ($Ϭ_{st}$);
2) the temperature of the cracking from the structural and / or temperature shrinkage stresses(T_c) and ultimate strength of these stresses (R_t);
3) thermal stress relaxation period (M_t).
In mechanical uniaxial tension under the scheme II, the following parameters are determined:
4) stress at uniaxial tensioning ($Ϭ_t$) and tensile strength (R_t);
5) deformation under uniaxial tensioning($£_t$);
6) elastic modulus (E);
7) complex elastic modulus(E *);
8) specific fracture work (A);
9) stress relieving period (m);
10) creep ($£_c$).
Under cooling, heating or isothermal holding of a floating sample in accordance with the scheme III the following pa-rameters are determined:
11) linear thermal expansion coefficient (λ);
12) structural transitions temperature (glass -transition T_g, fatigue T_f and others);
13) linear structural shrinkage (ξ_y).
Asphalt and cement concrete, plastics, metals and others can be tested at the plant. The automation unit is universal and can determine the full range of indicators characterizing the mechanical parameters, deformability of materials and their crack resistance.

4. DESCRIPTION OF SIMILAR PLANTS

The US-developed standard AASNTO TR 10-93 appeared in 1993 and in 2011 Europe standard EN 12697-46: 2011 to the unit CRT-APTTS [14] was developed. It gives an opportunity to test asphalt concrete in accordance with two loa-ding conditions: at uniaxial tensioning and at cooling of constrained at both ends specimen (Figure 3). Under these loa-ding conditions the same parameters as in the unit UONDA 14-20 are determined. Results of testing of asphalt concrete with bitumens, having differences in quality particularly in Fraas brittle point (Figure 4), at CRT-APTTS demonstrated the absence of differences in time-temperature values of cracking of asphalt concrete with these bitumens (Figure 5) [15].
There is no connection between the cracking temperatures and thermal stresses at break (Figures 5 and 6). Relationships shown in Figure 4-6 are quite right except for the data in Figure 5. It is doubtful that a significant difference in the com-position and performance of bitumen doesn't affect the crack temperatures of asphalt-concretes with these bitumens as the temperatures are the same.
In work [15] it is suggested to characterize crack resistance of asphalt-concretes by rheologic and strength properties: relaxation property level value and level of reliability in accordance with thermal crack resistance criterion. However, any method for determination of crack resistance of materials, working in coatings without ability of free movement, based on the rheological and strength properties of the material, as presented in [1-5,15], can give only properties chara-cteristics. These techniques don't take into account shrinkage temperature stresses in surface materials during cooling.

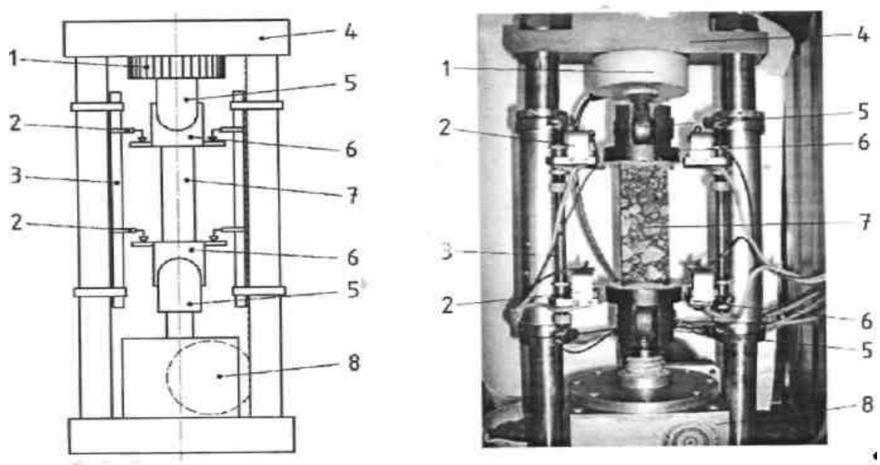


Figure 3: CRT-APTTS apparatus for uniaxial tension and thermal stress tests [14] . 1-loading member, 2- travel sensor, 3-base, eliminating thermal moving,4-crossbar,5-cardan suspension of a specimen, 6- adapter, 7-specimen, 8 - gear unit with step motor

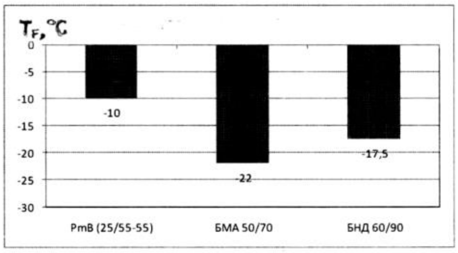


Figure 4: Fraas brittle point (TF) of bitumens: PmB (25 / 55-55), BMA 50/70 and 60/90 [15]

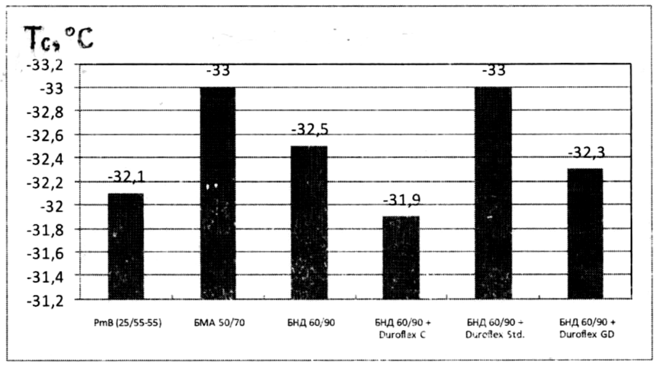
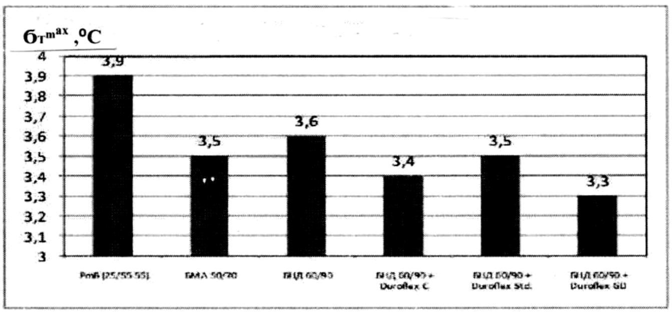


Figure 5: The cracking temperature of asphalt-concrete (Tc) with bitumens of different grades [15]

The stresses depend not only on viscoelastic properties but also on the linear thermal expansion coefficient. Shrinkage structural stresses under hard ening (aging) , depending on time are not considered too.



Figпre 6: Thermal stress at rupture ($б_T^{max}$) of the asphalt bitumen of different grades [15]

5. RESULTS OF TESTING AT UONDA 14-20 AUTOMATIC UNIT

Tests were conducted to determine certain properties of asphalt-concrete causing their crack resistance. During the tests on circuit I the effect of bitumen content in the mixture to thermal stresses and cracking temperature of asphalt concrete was determined. Samples having size 330 x 40 x 40 mm were produced by pressing at steady 4 minutes thermal rise up of pressure to 40 MPa with followed holding at this pressure for 3 minutes. Limestone having granularmetric content of the grade of G in accordance with GOST 9128-2009 was used as a mineral additive of the mixture. The content of bitumen of grade BN 60/90 (sample 3, Table 1) was changed by weight every 0.5% from 4 to 11%. The samples were tested in the unit at a cooling speed of 0.01°C/s. Figure 7 graph shows that cracking temperature has a minimum value when the content of bitumen in a mixture is 6.5%, which corresponds to the optimum, determined by the maximum compressive strength at 50, 20 and 0 °C.

σ_T^{max} ,°C

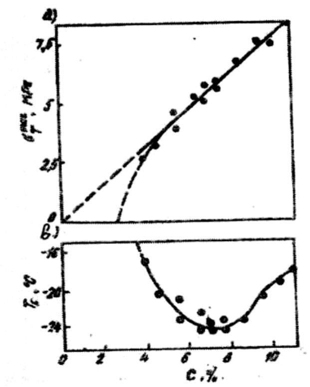


Figure 7: The dependence of the limiting thermal stress(σ_T^{max})and temperature of cracking of asphalt concrete (Tc) on the content of the bitumen in a mixture C.

The dependence of the limiting thermal stress at cracking of the asphalt concrete sample (σ_T^{max}) on the content of the bitumen in a mixture is a linear one with increasing amounts of bitumen. With a low content of bitumen in the mix (less than 5%) departure of σ_T^{max} from linearity is observed which caused by difficulties of producing of a dense sample under standard conditions of manufacture.

Asphalt crack resistance depending on the fractional composition of mineral aggregate is determined in accordance with two regularities. Firstly, fines - mineral powder in asphalt-due to their adsorption and structuring effect on the bitumen films contribute decrease of cracking temperature of asphalt concrete. Second, the coarse fraction of aggregate although to a lesser extent than the mineral powder, also provide some reduction of T_c due to reduction of thermal stressses in the bituminous films covering it. Therefore, asphalt concretes, containing a significant amount of mineral powder and coarse fractions of aggregate have the highest crack resistance in contrast to those ones containing aggregates of the more narrow fractions. This conclusion is supported by the lowest values of cracking temperature of asphalt concretes having gapped aggregate grading (Figure 8).

The effect of mixing temperature on T_c of asphalt concrete with different content of bitumen on different mineral aggregates (granite and limestone) is of great interest. As follows from the figure 9, there are mixing temperatures of asphalt mixes in which the cracking temperature of asphalt concretes (T_c) is the lowest . These mixing temperatures of

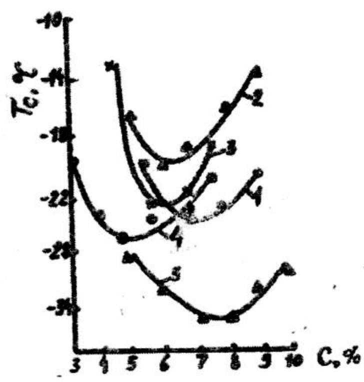


Figure 8: Dependence of the cracking temperature of asphalt concretes (T_c) on the content of the bitumen of C grade. Types of aggregate grading in accordance with GOST 9128-2009: 1 - sand D; 2 -grained B; 3 - grained A ; 4 -medium granular A; 5- medium granular having gapped aggregate grading A.

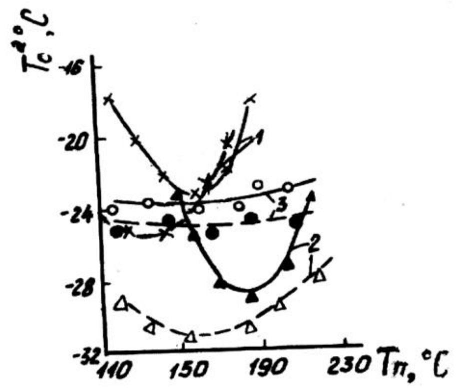


Figure 9: Dependence of cracking temperature of the asphalt concrete (T_c) from mixing temperature(Tп). (——) - limestone mixtures ; (- - -) - granite mixtures with a bitumen content of 5.5% - 1; 6.5% - 2; 7.5% - 3 .

Table 1: Properties of bitumens and asphalt concretes

Sample number	**Technology of production**	**Penetration,0.1 at temperature**		**Tensibility at 25 ^{0}C, cm**	**Temperature, ^{0}C**		**Penetration index**	**Asphalt concrete**		
		25	0		**Ring- and-ball softening point**	**Fraas brittle point**		**optimum mixing temperature, T_o, ^{0}C**	**cracking temperatureTc, ^{0}C**	
									at standard mixing temperature 155^{0}C	**at optimum mixing temperature**
1	Compounding of blo-wing to softening bo int 120 ^{0}C asphalt of deasphaltizing with extract of fraction 4	81	33	35	52.5	-21	+0.7	184	-33	-37
2	Cubed blowing of Romashkino oil tar with funnel viscosity at 80^{0}C 135 s	77	24	115	49.5	-11	-0.2	182	-31	-37
3	Vacuum concentra-tion of Romashkino oil leavings	75	16	>140	48	-10	-0.5	172	-25	-29
4	Compounding of asp-halt of deasphaltizing of Romashkino oil with extract of frac-tion 4 (95:5%)	83	12	>140	45	-8	-1.1	166	-23	-27

asphalt mixes can be called optimal -T_o. Optimum mixing temperatures of mixtures with a lower content of bitumen shift towards lower magnitude order of 20 ^{0}C and with high content of bitumen (higher than optimal), the optimum mixing temperature is indeterminate (Figure 9). T_o of the mixtures with granite aggregate shifts towards lover values of the order of 17 ^{0}S compared with mixtures on limestone. T_c of asphalt concrete on granite has lower values than the same but on limestone.

Determination of the cracking temperature of asphalt concretes, produced from mixtures with bitumens of different structural types at standard and optimum mixing temperatures allowed to establish (Table 1) that T_c of asphalt concretes made at optimum temperatures is 3-4 ^{0}C lower than T_c of asphalt concretes prepared at standard temperatures. There is a connection between Fraas brittle point of bitumens and T_c of asphalt concretes, though it is not quite correct (Table 1).

6. CONCLUSIONS

1.UONDA 14-20 automatic unit makes possible to determine a set of indicators which are responsible for crack resistance of road materials at three test circuits at temperatures from +70 to -70 ° C.: I - when cooling or heating - at thermal stresses of a sample constrained at both ends; II - at mechanical uniaxial stress; III - when cooling or heating -

at temperature deformation of a floating sample. Asphalt concretes, cement concretes, matrices, plastics, etc. in the initial state, and under certain conditions of aging (hardening) can be explored at the plant.

2.The minimum cracking temperature of asphalt concretes at a certain content of bitumen has been found.

3.Significant influence of mineral aggregate grain-size distribution on asphalt concrete cracking temperature. Asphalt with gapped grading of mineral aggregate has the lowest values of cracking temperature .

4.Optimal mixing temperature of asphalt concrete mixes To at whichtemperature cracking of asphalt has the lowest values has been established. The optimum mixing temperature of asphalt mixes with the granite mineral aggregates is 17 ^{0}C lower than of asphalt mixes with limestone. Cracking temperatures of asphalt concrete with granite is 2-4 ^{0}C lower than of the asphalt with limestone. Structural type of asphalt affects the optimal temperature of mixing of asphalt concrete mixture. The optimum temperature for the mixing of asphalt mixes with bitumens of similar penetration at 25 ^{0}C shifts from 166 to 184 ^{0}C as they transit from the structure of the sol to the gel (with -1.1 to +0.7 change in penetration index). Cracking temperatures of asphalt concrete are weakly correlated with bitumens Fraas brittle point.

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