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NECESSARY MEASURES FOR ENSURING THE QUALITY OF HOT MIX ASPHALT IN LITHUANIA

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Abstract. It was determined that poor quality of asphalt concrete is the main cause (65 %) of early fatigue cracking of asphalt concrete pavement of roads in Lithuania and neighbouring countries with similar climatic conditions. The poor quality of asphalt concrete is mainly predetermined by production errors of hot mix asphalt (HMA) and designed suboptimal mass ratio of constituents. The development of theoretical principles for producing the best componential composition of asphalt concrete is highlighted. Optimal values of the portions of coarse aggregate, fine aggregate, filler and bitumen recommended by different authors are given. The main causes of deviations from the optimal composition of HMA produced by asphalt asphalt mix plants of different generations are systematised. The dynamics of rapid cracking of asphalt concrete paving of Lithuanian roads is shown emphasising the inadequacy of HMA structure and properties to increased traffic intensity and axial workloads. The permissible values of asphalt concrete components, optimal under the actual climate and traffic conditions, ensuring highest asphalt concrete resistance to fatigue and rational (8–9 years) service life, during which the cracked pavement area does not exceed 8 %, are proposed. A quality assurance method has been developed based on mathematical statistical methods. It helps avoid deviations of component proportions, occurring in the process of production, from the project proportion and to increase the homogeneity of the product.

Keywords: hot mix asphalt (HMA), road pavement construction (RPC), asphalt mix (batch type**)** plant (AMP), quality assurance, componential composition, production quality, homogeneity.

1. Introduction

The plan of Lithuanian national road maintenance and development programme for 2002–2015 year (hereafter Programme) provides an essential improvement of the reliability of road infrastructure. Assurance of the mentioned conditions requires a better asphalt pavement and construction of the main motor roads: adequate smoothness of pavements, low cracking of the pavements and their construction, on adequate strength of road constructions and skid resistance. For rational distribution of means allotted for assuring of the mentioned conditions it is necessary to establish the permissible quality indices for asphalt concrete pavement and its construction.

The practice (Petkevičius, Sivilevičius 2000) has shown that in the climatic zone of Lithuania and neighbouring countries, where conditions for road bed and pavement are very complicated, about 35 % of untimely cracks appear due to an insufficient strength of the road pavement construction (RPC). 65 % of the pavement cracks is caused by inadequate quality of building material (primarily asphalt concrete). The implementation of the tasks provided in the Programme it is necessary to improve the quality of hot mix asphalt (HMA) for road surfacing. Short service life of road pavement when RPC is adequate is predetermined by an inadequate quality and density of HMA (Petkevičius, Sivilevičius 2000; Sivilevičius, Petkevičius 2002).

The quality of HMA depends not only on the quality of constituents and project composition but also on the quality of production. HMA of adequate project composition (answering the required properties for dense mix) can be easily compressed with modern equipment. It is a more complicated task to choose the optimal project HMA for concrete functioning conditions. From the first attempts to deal with the problem in 1930, it remains unsolved. The greatest contributions to its solution in the post-war years (after 1945) were made by researchers of USA, UK, Germany, France, Italy, Japan, Switzerland, Holland, Belgium, Denmark, Poland, Russia etc.

At the beginning of the 20th century, the principles of ideal gradation were applied when determining the mineral composition of asphalt concrete. Namely at that time Fuller developed a theory of ideal gradation of minerals. In about 1920, Bolomej and Tolbot-Richard (USA) proposed a dense mix curve, whereas the Federal Laboratory of Minerals Research of Switzerland also proposed a gradation curve for dense mixes (Roberts *et al.* 2002). Though different, the all gradation of mineral mixes proposed before 1930 answered the required conditions for dense mixes. The density of mixes differed by no more than 1,0–1,5 %. The mentioned experience was applied in many other countries for developing dense HMA curves (Roberts *et al.* 2002). Yet the available experience had to be promoted. Further research showed that under different service conditions (climate, soils and their moisture regime, traffic volume and composition, and RPC) the composition of asphalt concrete best applying to these conditions may vary considerably. Initially, a group of researchers assumed that only a non-contact structure of asphalt concrete could be optimal. Another group adhered to the opinion that both contact and non-contact structures could be optimal. Further investigations in many countries confirmed the soundness of the second assumption. It was proved that depending on service conditions of asphalt concrete in the pavement (local climate, soil properties and moisture regime, RPC etc) different HMA compositions (Sivilevičius, Petkevičius 2002) may turn out optimal (ensuring the longest service time): from cast to carcass asphalt concrete containing a great portion (≥ 60 of the total mass %) of coarse grains (coarser than 5 mm). Analysis of many researches showed that even despite a high variability of local service conditions of asphalt concrete in the pavement and despite different materials used for producing HMA – Russia, USA, the United Kingdom, Poland, Lebanon, Lithuania etc – there are certain limits for different HMA components when the mix and asphalt concrete best apply to the mentioned variable service conditions.

The limits of most universal HMA are the following: grains of crushed material coarser than 5 mm (coarse aggregate) CA = 40–60 mass %, crushed material composed of 0,071 (0,075)–5 mm (fine aggregate) grains FA = 24–52 mass %, material composed of grains finer than 0,071 (0,075) mm (filler) F = 8–16 mass % and asphalt cement (bitumen) B = 5,5–7,0 mass %. The composition of HMA best to apply to variable service conditions is the following: CA = 50 mass %, FA = 38 mass %, F = 12 mass %, and B = 6,25 mass %. Investigations of optimal composition of HMA targeted at making optimal use of local materials and for an prolongation of its service life in the road pavement are continued: in Lithuania (Петкявичюс, Подагелис 2005), Saudi Arabia (Samynoureldin 1997), USA (Kanitpong *et al.* 2005), and other countries.

Experience of different countries since the beginning of HMA production in 1965 until 1990 (Бункин 2002; Mallick, Brown 1999; Parker *et al.* 2000; Petkevičius, Christauskas 2006; Sivilevičius 2002; White *et al.* 2002) and later shows how difficult it is to achieve an optimal equivalence of HMA composition to its project composition. Analysis of works (Бункин 2002; Mallick, Brown 1999; Parker *et al.* 2000; Petkevičius, Christauskas 2006; Sivilevičius 2002; White *et al.* 2002) shows that the main causes of failure to solve the problem are the following:

- imperfection of asphalt mix plants (AMP) at the beginning of HMA production (1930–1965) in all countries and from 1965 until 1995 in the technically and economically backward countries (Russia and other former countries of the Soviet Union etc);
- low quality of materials used for HMA production: poor homogeneity of gradation and other properties, low quality bitumen (on 1930–2007);
- imperfection of the methods for HMA quality assurance;
- low qualification of HMA producers (until 1965 in Russia and other countries of the USSR etc).

In recent years (after 1995), many countries (including Lithuania) use modern AMP and the qualification of HMA producers has been improved. Yet the problem persists as minerals used for HMA production are not always of a good quality and HMA quality assurance methods are not always workable.

The present work aim is to propose the technologies of producing in Lithuania HMA of optimal composition and homogeneity.

2. Assessment of the actual situation in Lithuania

The traffic vehicles velocity depends on the conditions of pavement. This conditions in Lithuania compared with other East European counties is very good, yet according to the requirements followed by the developed West European states are only satisfactory. Some time ago, the asphalt concrete pavement of Lithuanian roads mainly would crack under a recurring impact of freeze and water. Plastic defects almost would not occur. In recent years, the status of the pavement of Lithuanian roads has been rapidly deteriorating. Particularly development of rutting has intensified

(Laurinavičius, Oginskas 2006). Fatigue cracks also occur in abundance due to an increased number of heavyweight vehicles on the main roads (Butkevičius *et al.* 2007; Šiaudinis, Čygas 2007). The strength and roughness of pavement construction were not designed for high loads. From 1993, repair works have been reduced due to the lack of financing. The research results obtained by the Transport and Road Research Institute show that due to the mentioned causes road pavement defects became more frequent (degree of road disintegration *D* increases) and road pavement structures are gradually weakening. In the main and country roads, the structural number of construction (*SNC*) describing the RPC strength has been annually reducing by 2 % on average (Sivilevičius, Petkevičius 2002). The *SNC* in the main roads has been increasing only since 2005, when urgent measures for strengthening the road pavement construction were taken. Also investigations aimed at improving the density of materials (Markauskas, Kačianauskas 2006) were carried out.

In recent years, the international roughness index (*IRI*) (m/km) have been improving as a result of better quality repair works. Since 1992, its average annual increase has been: for motorways by 0,041 m/km, for other main roads – 0,054 m/km and national roads – 0,054 m/km.

Under these conditions, the RPC service life between major repairs was considerably reduced: the required Lithuanian standard (of 1987) for RPC (the 1st and higher category of roads) service life between repairs was T_k = 14 years, but we have determined that in 2002 the factual average service life of RPC between repairs (hot method "Remixer 4500RX" recycling of asphalt concrete pavement) was T_k = 9 years. An insufficient adhesion of the layers of asphalt concrete is one of the causes of reducing of the service life of asphalt concrete pavement (Sivilevičius, Petkevičius 2002). This problem also exists in other countries (Ziari, Khabiri 2007).

The reducing strength of RPC and increasing scale of the pavement disintegration are predetermined not only by an increasing traffic volume of heavyweight vehicles but also by an inadequate quality of HMA used for road pavements.

The construction of AMP produced since the end of the 4th decade of the 20th century has essentially changed in the last few decades. They have become more universal and their productive capacity has increased. The AMP production technologies have advanced. Certain operations and eventually the whole production process have been automated and computerised (Jones 1986; Sivilevičius 2002). The mainline processes also took place in Lithuania. In the 7th–8th decades of the last century, in order to improve the quality and homogeneity of HMA, mathematical statistical and other methods were applied for HMA quality control and assurance and consistently improved in the USA, Germany, Great Britain etc (Бункин 2002; Kanitpong *et al.* 2005; Parker *et al.* 2000; White *et al.* 2002) and in Lithuania (Petkevičius, Christauskas 2006; Sivilevičius 2002).

The European producers of HMA usually use a batch-type AMP when the mixture of mineral materials is screened into 3–5(6) hot fractions and the latter are dosed with other materials (imported filler, reclaimed dust and bitumen). The constituent batches of hot asphalt mixes are then blended in a mixer. In the USA and Canada, a continuous type AMP of simple construction better suited for producing HMA from highly homogeneous mineral materials is used (Jones 1986; Sivilevičius 2002).

Lithuania does not produce AMP. They are imported from the following companies of Germany, Italy, Finland, Ukraine, and Russia: Ammann, Benninghoven, VEB Teltomat, Maschinen GmbH, Marini, Machinery, Dormašina. The high performance of these AMP capable of producing highly homogeneous HMA is not made full use of in Lithuania because the valid normative does not commit to production of highly homogeneous HMA strictly following the projected componential composition. Due to the mentioned causes, the factual service life of asphalt concrete pavements has been permanently reducing in motorways. Today it is very low T = 5,5 years (Sivilevičius, Petkevičius 2002). Lithuania fails to produce homogeneous HMA even with modern AMP because low homogeneity (according to gradation) minerals are used. Our analysis shows a necessity of more effective measures to ensure the adequate quality of HMA in Lithuania.

3. Optimal HMA compositions under Lithuanian conditions

Under the conditions of increasing portion of heavyweight vehicles on the Lithuanian roads, fatigue resistance predetermining the adequate service life of asphalt concrete in the road pavement becomes its main required characteristics. The importance of this index was also confirmed in the USA, Russia, West European and many other countries. Fatigue resistance is the major criterion in determining the optimal composition of asphalt concrete. It is reported in literary sources that HMA of optimal composition, also characterised by other best properties and ensuring the best status of asphalt concrete pavement (evaluated by the degree of disintegration *D* and other indices), ensures the highest fatigue resistance. By a choice of asphalt concrete composition it is possible to control the disintegration process of asphalt concrete cover. The fatigue resistance of asphalt concrete depends on its mechanical indices (resistance to flexion $R_l^{(a)}$ and resistance of water-saturated asphalt concrete to compression R_v) (Петкявичюс, Подагелис 2005):

$$N = R_l^{(a)1,12} \cdot R_v^{1,25} \cdot 10^3 , \quad (1)$$

and on its composition (Table 1):

$$\ln N = 11,51 + 0,437CA - 0,326CA^2 - 0,292CA^3 + 0,351\,F - 0,764\,F^2 + 0,074\,F \cdot B + 2,002B - 0,872B^2 - 1,214B^3. \quad (2)$$

It was determined that the following composition ensures the longest service life $T = 11$ m of asphalt concrete pavement under cyclic loads: $CA = 47{,}8$ of the mass %; $FA = 41{,}8$ of the mass %; $F = 10{,}4$ of the mass %; $B = 6{,}8$ of the mass %.

Asphalt concrete is not an ideally homogeneous material: its composition always varies within certain limits. It was determined that even small changes of asphalt concrete composition may ensure $T = 8{,}5\ y - 11{,}0\ y$ service life (Петкявичюс, Подагелис 2005; Petkevičius, Sivilevičius 2000; Sivilevičius, Petkevičius 2002). In order to ensure $T \geq 8{,}5$ years service life of asphalt concrete pavement, it is necessary to observe the permissible limits of HMA componential composition (Table 1).

Our experimental investigations of pavement disintegration, carried out in the Lithuanian highways and streets, showed (Петкявичюс, Подагелис 2005) that in the course of time (from 1985 until 2003) and with an increasing portion of heavyweight vehicles in the traffic flow, the composition of asphalt concrete whose service life was longest has been approaching the fatigue resistant composition of asphalt concrete (Table 2).

The difference between the data presented in Tables 1 and 2 could be even smaller (meaning better quality and longer service life of asphalt concrete pavement) if such materials as granite, crushed stone and bitumen were not economised when surfacing motorways (not many motorways stretches were found with $CA \geq 40{,}0$ of the mass % (or $CA \geq 56{,}5$ of the mass %) and asphalt cement $B \geq^3 6{,}2$ of the mass %).

For achieving the asphalt concrete service life $T \geq 8{,}5$ year in the Lithuanian motorways, it is necessary to ensure the necessary homogeneity of HMA and asphalt concrete which is expressed as the permissible (admissible) spread range variation δ_{adm}, permissible overshoot of average value of each component (CA, FA, F, B) from the project values Δ_{adm} and permissible standard deviation (s) of each component σ_{adm}.

The value of δ_{adm} is derived by the equation:

$$\delta_{adm} = T_{\max} - T_{\min}, \quad (3)$$

where $T_{\max}$ and $T_{\min}$ – the highest and lowest permissible values of the content of asphalt concrete component (Table 1).

Knowing the probability $P(T_{\min} < X < T_{\max})$, when $P = P_{adm}$, of random value getting within the permissible interval of normal distribution lot limited by values $T_{\min}$

Table 1. The optimal composition of blacktop of asphalt concrete under cyclic loads ensuring asphalt concrete service life $T \geq 8{,}5$ was determined according to results of fatigue test of HMA samples (40 mm × 40 mm × 160 mm balks)

Components of asphalt concrete	Portions of components, of the mass %			
	optimal	permissible values		permissible variation, δ_{adm}
		maximal, T_{max}	minimal, T_{min}	
Coarse aggregate: grains CA coarser than 5 mm (2 mm) in size (CA)	47,5 (64,0)	55,0 (71,5)	40,0 (56,5)	15,0
Fine aggregate: grains FA 0,071–5 mm (0,09–2 mm) in size (FA)	42,5 (24,5)	52,0 (34,0)	33,0 (15,0)	19,0
Filler: grains F finer than 0,071 mm (0,09 mm) in size (F)	10,0 (11,5)	12,0 (13,5)	8,0 (9,5)	4,0
Bitumen (B)	6,8	7,2	6,4	0,8

Table 2. Rational composition of asphalt concrete in the blacktop of road pavement determined according to the investigation (in 1997–2003) data of road pavement disintegration

Components of asphalt concrete	Portions of components, of the mass %			
	rational	permissible values		permissible variation, δ_{adm}
		maximal, T_{max}	minimal, T_{min}	
Coarse aggregate: grains CA coarser than 5 mm (2 mm) in size (CA)	41,5 (58,0)	45,5 (62,0)	37,5 (54,0)	8,0
Fine aggregate: grains FA 0,071–5 mm (0,09–2 mm) in size (FA)	47,0 (29,0)	53,0 (35,0)	41,0 (23,0)	12,0
Filler: grains F finer that 0,071 mm (0,09 mm) in size (F)	11,5 (13,0)	13,5 (15,0)	9,5 (11,0)	4,0
Bitumen (B)	6,2	6,8	5,6	1,2

and $T_{\max}$, we may derive indices Δ_{adm} and σ_{adm}:

$$P(T_{\min} < X < T_{\max}) = F(t_2) - F(t_1) = F(t), \quad (4)$$

$$t_1 = \frac{(\Delta_{adm} + x_p) - T_{\min}}{\sigma_{adm}}, \quad (5)$$

$$t_2 = \frac{T_{\max} - (\Delta_{adm} + x_p)}{\sigma_{adm}}, \quad (6)$$

where $F(t)$ – Laplace function whose value is determined by mathematical statistical tables; x_p – project value of component mostly coinciding with the arithmetic mean of the limits of gradation:

$$x_p = \frac{T_{\min} + T_{\max}}{2}. \quad (7)$$

At probability $P = P_{adm} = 99,73$ % it is possible to determine the interdependence of indices Δ_{adm} and σ_{adm}:

$$\Delta_{adm} = \delta_{adm} - 6\sigma_{adm} \approx Z_p \sigma_{adm}, \quad (8)$$

$$\sigma_{adm} = \frac{\delta_{adm} - \Delta_{adm}}{6}, \quad (9)$$

where Z_p – the index of normal distribution, its value (determined by mathematical statistical tables) is $Z_p = 0,674$.

Values of indices δ_{adm}, Δ_{adm} and σ_{adm} (for HMA components) are given in Table 3. Ensuring the composition and homogeneity of asphalt concrete within the established limits (Tables 1–3) will ensure $T \geq 8,5$ years service life of asphalt concrete pavement under cyclic traffic loads. This value of service life till major repairs is sufficient for the Lithuanian main roads pavement (Sivilevičius, Petkevičius 2002). This asphalt concrete composition is close to the optimal one and the component values are rational. Our investigations (Petkevičius, Christauskas 2006; Sivilevičius 2002) showed that Lithuanian AMP can produce HMA of the indicated homogeneity (Table 3).

4. The quality indicators technological process of HMA production

It is necessary to distinguish between the HMA quality and the HMA production quality. The quality of HMA production is characterised by % of its mass meeting the job mix formula or normative documentation quality (componential composition, temperature etc) requirements. It is also characterised by technological process perfection and state.

The whole technological process and discrete operations of HMA production are affected by systemic and random factors. The quality of production varies as a result of varying quality of initial mineral materials used in HMA production. The varying range also depends on the technical parameters of AMP and control and regulation of technological process of HMA production.

Table 3. Values of δ_{adm}, Δ_{adm} and σ_{adm} of the mass % determined by fatigue analysis of HMA samples (balks) when $T \geq 8,5$ years

Index and its sign	Coarse aggregate	Fine aggregate	Filler	Bitumen
Permissible variation δ_{adm}	15,00	19,00	4,00	0,80
Permissible average deviation from job mix formula value Δ_{adm}	1,50	1,90	0,40	0,08
Permissible standard deviation σ_{adm}	2,25	2,85	0,60	0,12

The quality of HMA is adequate if the following specification is fulfilled:

$$\Delta_f \leq \Delta_{adm}, \quad (10)$$

$$s_L \leq \sigma_{adm}, \quad (11)$$

where Δ_f – deviation of HMA component from the job mix formula value x_p; s_L – factual sample standard deviation of this content component.

When the quality variations of the cold initial mineral materials and bitumen designed for HMA production are small, the produced HMA quality depends on the production quality. In Lithuania, the problem of the quality of initial mineral materials yet has not been fully solved: their quality indices vary within a rather wide range.

During the production of HMA with batch type AMP, the batch of each component deviates by value Δ_b and varies within the range $6\sigma_b$. The HMA batches components may be very well, averagely and poorly homogenised. When the batches of HMA components do not deviate from the job mix formula values ($\Delta_b = 0$), the average composition of lot HMA is homogeneous (Figs 1a–1c). In a batch composed of discrete mixes when the lot of HMA components deviates from job mix formula values ($\Delta_b \neq 0$), the content deviations of components Δ_L are derived using (Fig 1d):

$$\Delta_L = \mu - x_p \approx \bar{x} - x_p, \quad (12)$$

where μ, $\bar{x}$ and x_p – average content value of HMA component, average value of taken samples (arithmetic mean) and job mix formula value. If the tested sample is large enough, $\bar{x}$ is close to μ and s is close to σ; thus the values $\bar{x}$ and s of the sample could be used as the statistical indices of population.

Deviation of the component content in the produced j^{th} batch of HMA from the job mix formula value Δ_{bj} is calculated by the formula:

$$\Delta_{bj} = \bar{x}_{bj} - x_p, \quad (13)$$

where $\bar{x}_{bj}$ – average content of the component of the produced j^{th} batch of HMA determined from one or several ($i = 1, 2, ..., n$) random elementary samples, which were tested without blending:

$$\bar{x}_{bj} = \frac{\sum_{i=1}^{n} x_{ij}}{n}, \quad (14)$$

where x_{ij} – the component content in i^{th} elementary sample of j^{th} batch of HMA, of the mass %; x_p – the job mix formula value in the produced HMA, of the mass %.

Deviation of the component content in a produced lot of HMA (the mix produced according to a single composition job mix formula of the same brand and of the same materials during one working shift or in a shorter period of time) from the job mix formula value Δ_L is calculated by the formula:

$$\Delta_L = \frac{\sum_{j=1}^{m} \Delta_{bj}}{m} = \frac{\sum_{j=1}^{m} \left(\bar{x}_{bj} - x_p\right)}{m}, \quad (15)$$

where m – number of tested batches of the produced HMA lot from which the samples were taken ($j = 1, 2, ..., m$).

Homogeneity of the j^{th} batch of the produced HMA, depending on the quality of material blending in the mixer, is described by the sample standard deviation in the content of the selected component:

$$s_{bj} = \sqrt{\frac{\sum_{i=1}^{n} \left(x_{ij} - \bar{x}_{bj}\right)^2}{n-1}}. \quad (16)$$

The homogeneity index of a lot of HMA, composed from m homogenised batches (Fig 1a), could be indicated by the sample standard deviation s_L, calculated by the formula:

$$s_L = \sqrt{\frac{\sum_{j=1}^{m} \left(\bar{x}_{bj} - \bar{\bar{x}}_{bj}\right)^2}{m-1}}, \quad (17)$$

where $\bar{\bar{x}}_{bj}$ – sample arithmetic mean of the component of batches in the produced HMA lot is:

$$\bar{\bar{x}}_{b} = \frac{\sum_{j=1}^{m} \bar{x}_{bj}}{m}. \quad (18)$$

When using the rule which says that a standard deviation of different values of a variation series is equal to the standard deviation of the difference (deviation) from these values and a constant value (for example, from the job mix formula value of the component x_p), it could be derived that $s_L = s_\Delta$.

The components of the produced HMA batches are not usually blended in a way that a percentage of each of them in all places of its volume is equal, ie that the batches are absolutely homogenised (Figs 1b–1d). When a variation in the content of HMA batches components is sufficiently large (they are not homogenised), the homogeneity of the lot is showed by the sample standard deviation s_L, which describes a dispersion in the group (in a batch) and between the groups (between the batches):

$$s_L = \sqrt{\bar{s}_b^2 + s_\Delta^2}, \quad (19)$$

where $\bar{s}_b$ – the corrected sample standard deviation of the component content, showing an average homogeneity of the HMA lot (of all m batches not blended together) and calculated by the formula:

$$\bar{s}_b = \sqrt{\frac{1}{n_1 + n_2 + ... n_m - m} \sum_{j=1}^{m} \left(n_j - 1\right) s_{bj}^2} = \sqrt{\frac{1}{k} \sum_{j=1}^{m} k_j s_{bj}^2}, \quad (20)$$

where k_j – number of degrees of freedom in random elementary samples of the produced j^{th} batch of HMA $\left(k_j = n_j - 1\right)$, $k = \sum_{j=1}^{m} k_j$; s_Δ – sample standard deviation of the deviation of the component content Δ_{bj} from the job mix formula value x_p in all tested m batches of a lot of HMA:

$$s_\Delta = \sqrt{\frac{\sum_{j=1}^{m} \left(\Delta_{bj} - \Delta_L\right)^2}{m-1}}. \quad (21)$$

The illustration shows the interrelation of componential composition Δ_L and standard deviation σ_L values in a lot of HMA mixes and Δ_B and σ_B values in one batch HMA mix in the course of time:

a) constant batches composition: $\Delta_b = \Delta_L = 0$; $\sigma_b = \sigma_L < \frac{\delta_{adm}}{6}$; b) constant trend: $\Delta_b = \Delta_L = 0$; $\sigma_b = \frac{\delta_{adm}}{6} = \sigma_L$; c) constant trends: $\Delta_b = \Delta_L = 0$; $\sigma_b = \sigma_L > \frac{\delta_{adm}}{6}$; d) changing trend (increase and reduction): $\Delta_b \neq 0 \neq \text{const}$; $\Delta_L = \frac{\sum \Delta_b}{n}$; $\sigma_b > \frac{\delta_{adm}}{6} = \text{const}$; $\sigma_b < \sigma_L$.

HMA homogeneity according to the batch content standard deviation values σ_b (mass %) shows the quality of HMA mixing in a mix. We determined the minimal values of standard deviation σ_b of the content of HMA components at sufficient duration of HMA mixing t_r = 45–60 s (Table 4).

Using a special truck-type sampler 21 to 25 random elementary samples were taken from one batch. Since the number of random elementary samples of one batch was very large, the index of the sample s_b (Table 4) could be used as the population index σ_b.

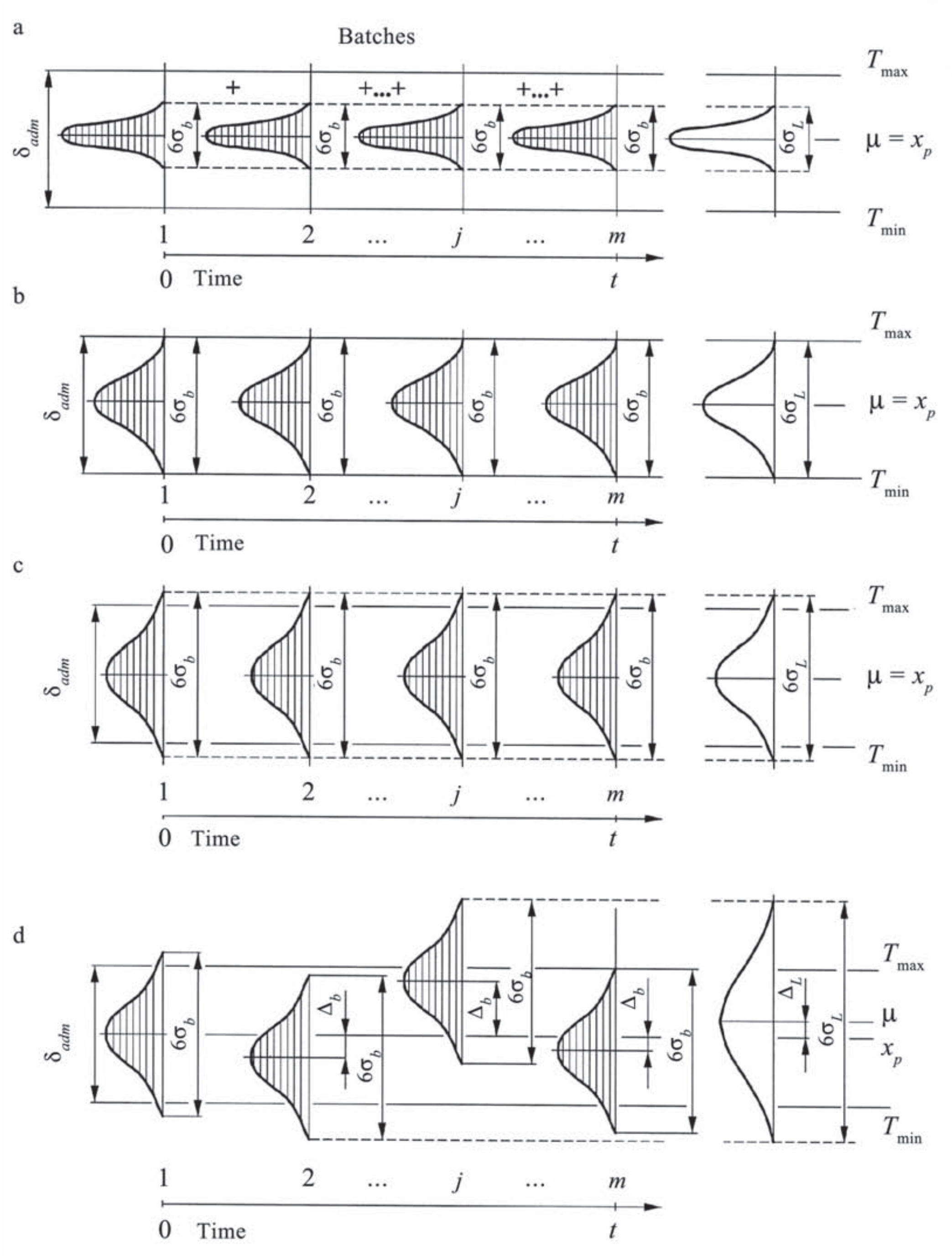

Fig 1. Dynamics of relationship between Δ_L and σ_L values in a lot of HMA components and Δ_b and σ_B in a batch mixture in the course of time

Table 4. Homogeneity of HMA mixes according to the values of standard deviation σ_b of the content of batches HMA components

HMA components	Minimal values of batch HMA componential homogeneity index σ_b, mass %
Coarse aggregate (*CA*)	0,30
Fine aggregate (*FA*)	0,30
Filler (*F*)	0,20
Bitumen (*B*)	0,15

Comparison of σ_{adm} value for bitumen in asphalt concrete σ_{adm} = 0,12 mass % given in Table 3 with the smallest value σ_b = 0,15 mass % for bitumen in HMA given in Table 4 revealed that the batch type AMP cannot ensure the HMA homogeneity according to the content of bitumen and can hardly ensure homogeneity according to the content of filler.

Analysis of the technological process of HMA production using batch type AMP allowed determining the main pattern of the process and parameter dynamics. The duration of HMA blending varied but little: the values of standard deviations s_t of observed blending operations did not exceed s_t = 1,5–1,6 s. These variations of blending duration had no significant influence on homogeneity. The air pressure in the pneumatic control system P_0 was on the average $\bar{P}_0 = 0,4$MPa the standard deviation being s_{P_0} = 0,025–0,040 MPa. When more than one plant uses one and the same compressor system, the value of s_{P_0} may increase to 0,1 MPa and even more (due to temporal irregularity of s_{P_0} air use). When the values were $P_0 \le 0,4$ MPa and $s_{P_0} \le 0,04$ MPa, the air pressure produced no major influence on HMA homogeneity.

The temperature of bitumen supplied from the AMP vats for HMA production usually was stable: the variation interval of its average values during shifts was 149–151 °C, standard deviation being s = 0,4–0,6 °C. Yet the temperature of HMA produced by different shifts varied within the range of 125–175 °C and its standard deviations exceeded 10 °C. Temperature variations were mainly predetermined by variations of moisture of initial mineral materials. It was determined that when the average moisture of a mix of initial mineral materials (granite crushed stone 3–10 mm in diameter or granite sitting 0–3 mm in diameter) was $\bar{W}_p \le 4,5$ % and its standard deviation was $s_{Wp} \le 0,09$ %, the probability of assurance of the necessary HMA temperature (140–160 °C) was 95 %; when these values were $\bar{W}_p \le 3,5$ % and $s_{Wp} \le 0,08$ %, the assurance probability was 99,73 %.

It was determined that for producing a fine-gradation HMA by batch type AMP D-597, D-597A and D-508-2A, the rational mass of mix is $Q_m^{(r)} \ge 500$ kg the max being $Q_m = 750$ kg (the rational coefficient of mixer filling is $K_u^{(r)} \ge 0,7$) and the rational mixing time is t_r = 45–60 s. Ensuring the indicated values $Q_m^{(r)}$, $K_u^{(r)}$ and t_r, of indices Q_m, K_u and t in the technological process helps reach the highest homogeneity of batches mixes of HMA (Table 4).

In recent years, some Lithuanian companies producing HMA have procured new models of batch type AMP. They are used in for producing more than 80 % of HMA. Using the new AMP models for HMA production, the variations of mineral components mainly depend on the variation of gradation of initial mineral materials and on the actions of the technological process operator. When the operator strictly follows dosage requirements for materials, when blending process is sufficiently long ($t \ge 45$ s) and when the content of screened mineral materials varies within a narrow range in the hot bin sections, the degree of HMA homogeneity is sufficiently good (Sivilevičius 2005).

5. Conclusions

1. The authors of the present article began to apply statistical methods of control, regulation and quality assurance of the technological process of HMA production in the 70ies of the 20th century and were the first to achieve good practical results. Homogeneity of HMA produced in Lithuania has been improved considerably and its componential composition usually satisfied the established permissible values.

2. The reaches of motorways pavement constructed applying statistical control and regulation methods in the technological process of HMA production functioned without significant disintegration signs (in each of the analysed sectors, the area of disintegrated pavement did not exceed 8 % of the total pavement area) for 8–9 years. Meanwhile, the service life of sectors, where these methods were not applied, was 5–6 years.

3. Among one of the major causes of an insufficient HMA homogeneity we can mention the segregation of dosed hot mineral materials fractions in batch type AMP supply bins. Anti-segregation equipment developed and used by the authors allowed to increase homogeneity of hot fractions by 1,5–2,0 times and to reduce dispersion of componential composition of produced HMA.

4. The longest service life in the motorways pavement under the ever increasing loads of heavyweight vehicles was characteristic of asphalt concrete with componential composition almost identical to the composition of fatigue-resistant asphalt concrete. This composition is optimal under the Lithuanian motorways conditions.

5. Our long-term experience and research show that application of the mandatory measures for HMA quality assurance in Lithuania enables producing HMA of rational (close to optimal) componential composition and rational homogeneity using older or modern AMP. Of special importance are the actions of the technological process operator who must choose relevant tolerance weight of initial and finally proportioned materials, control factual productive capacity of equipment, working regime (minimising the variations of the content of mineral materials in bins in the process of production), and duration of blending the HMA components.

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