Development of a Polymer-Bitumen Binder for Road Building Taking Into Account the Specific Features of Raw Material in the Samara Region

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Abstract

A mathematical model for the determination of the quality of polymer-bitumen binder for road construction on the basis of the raw material from local oil-processing plants was developed. The model obtained on the basis of investigations into the selection of the optimal composition of modified road bitumen allows one to predict the quality of the product depending on the composition of the initial raw material, thus providing the flexibility of the process of obtaining polymer-bitumen binder.

INTRODUCTION

More than 70 % of the total length of public roads does not meet modern requirements because of insufficient financing of road building, increasing requirements to paving, and increasing load on the roads. According to the diagnostic data of the federal road network, nearly 28 thousand kilometres of roads need repair, while more than 4 thousand kilometres need reconstruction. The main problems here are connected with the insufficient strength of road paving, unsatisfactory adhesion, absence of the necessary evenness, and low carrying capacity [1]. One of the main reasons of the indicated shortcomings is the low quality of bitumen, the most important road material. Commercial bitumen supplied to the road-making organizations in some cases does not meet the requirements of the State Standard (GOST), including such important characteristics as softening temperature, stretchability at 25 and 0 °C, brittle temperature, adhesion to stone materials.

The foreign and home experience shows that at present one of the possible ways to improve the quality of binding materials for road making is to modify them with various additives [2]. The choice of modifying agents should be made taking account of the efficiency of an additive affecting the physical and mechanical characteristics of bitumen and economic substantiation. The additives are classified according to the areas of their application and the character of action on bitumen: plasticizing (oligomers, oil), structuring (synthetic caoutchouc, thermoplastic elastomers, SKEPT type copolymers) and mixed (residues of styrene or benzene distillation, shale softener) [3].

With the use of a polymer bitumen binder (PBB), structuring additives that provide the necessary set of mechanical properties within a broad temperature range are the most important ones. For example, it is necessary to mention a wider temperature range of the performance capacity of polymer-bitumen materials in comparison with conventional bitumen materials that are used in all the climatic regions of the country without accounting for this parameter.

When working with bitumen modified with polymers, it is necessary to take into account the properties and features of the structure of the initial material, which will allow one to avoid unreasonable expenses due to the low efficiency of expensive polymers in such a material-consuming area as road-building.

In order to understand the interconnection between the structure of bitumen and changes in rheological properties due to the modification with polymers, attention should be paid to the composition of the initial bitumen. Since bitumen is rather complicated for the analysis of separate molecular types, it is generally accepted to separate it into several component fractions by means of precipitation and chromatography. The majority of fractioning procedures result in the separation of bitumen into the pyrobitumen (precipitated) and petrolene (soluble) phases. The latter phase can further be fractioned, for example, into saturated compounds, aromatics and tar. The pyrobitumen fraction consists of polycyclic condensed ring systems containing heteroatoms and aliphatic side chains with the molecular mass from several hundred to hundred thousand units [4]. The group composition of bitumen determines their characteristics: pyrobitumen determines hardness and high softening temperature, tar determines elastic properties and penetration, petrolenes represent a medium in which tar is dissolved and pyrobitumen is swelling.

The addition of polymers with molecular mass similar to of higher than that of pyrobitumen disturbs the phase equilibrium because both pyrobitumen and the polymer have the ability to swell in the petrolene phase thus affecting its dissolving ability. Depending on the ratio of the required and available dissolving ability, phase separation can occur. Bitumen with the high content of petrolene phase provide more rapid swelling of the polymer than bitumen with high pyrobitumen content. However, in some cases rapid swelling of the polymer is undesirable and depends on the type of equipment used (mixers with high or low sharing force) and on the kind of polymer (powdered or lump) [6].

The pyrobitumen content should also be balanced carefully. A definite amount of asphaltenes is necessary for association with the polymer which increases resistance of flow and rises softening temperature. The admissible concentration of pyrobitumen depends on polymer content, molecular masses of the polymer and pyrobitumen, and on the aromaticity of bitumen [7] because a polymer with low molecular mass may be added into bitumen with high pyrobitumen content, while high aromaticity defines the low softening temperature of the resulting PBB.

So, in order to utilize the characteristics of the polymer in full, it is necessary to choose an optimal bitumen and polymer which would simplify the efficiency of mixing procedures and acceptable properties of the resulting PBB. The technology of introduction of additives should be rather simple and flexible with respect to the quality of the initial raw material. In addition, modification should not cause a substantial increase in the cost of road paving.

The goal of the present work was to adapt the existing procedure of obtaining PBB (based on divinyl styrene thermoplastic elastomer DST-30-01) used in the construction of bituminous concrete pavement (the procedure accepted by SoyuzdorNII Institute, Moscow) to the raw material from the regional oil-processing plants (OPP).

EXPERIMENTAL

The initial raw material was bitumen of BND 90/130 grade from the Novokuybyshevo OPP (NkOPP) and BDN 60/90 from the Syzran and Kuybyshev OPP (SOPP and KOPP, respectively). The hydrocarbon group composition of bitumen, bitumen modifier thermoplastic elastomer DST-30-01 (Voronezh SC Plant) and tar from KOPP and NkOPP is presented in Table 1 [3].

In our opinion, the technology of bitumen modification with polymer additives is determined mainly by the method of adding the modifying agents. Two versions are possible: dissolution of the additives in the initial bitumen, or dissolution of additives in a solvent followed by compounding of the solution with bitumen. Recommendations of SoyuzdorNII [8] foresee obtaining PBB by adding 2–2.5 % DST from a 10–20 % solution in hydrocarbon solvents (xylene, benzine, kerosene, solvent, diesel fuel, TS-1) to the road bitumen heated to 90–110 °C. We proposed to dissolve DST in tar

TABLE 1

Hydrocarbon group composition of bitumen under investigation, mass %

Hydrocarbon group	BND 90/130	BND 60/90	
	NkOPP	SOPP	KOPP
Oil	50.3	51.8	50.8
Including:			
paraffin-naphthene and monoaromatic	24.2	32.9	25.1
biaromatic	12.3	10.6	16.6
polyaromatic	13.8	8.3	9.3
Tar	31.5	26.3	30.7
Asphaltenes	18.1	21.7	18.3
Carbenes, carboid	0.2	0.2	0.2

and to use the polymer tar concentrate as an additive to bitumen.

RESULTS AND DISCUSSION

A disadvantage of the first version (dissolution of DST in bitumen) should be noted. The time of complete dissolution of DST in commercial bitumen is about 4–5 h; during this time the system should be kept at a temperature of 130–170 °C, which cannot but affect the quality of the resulting PBB. Saturation with air caused by long-term mixing in an open system is undesirable both for bitumen and for the polymer. One cannot also discard limiting temperatures due to thermal stability of DST.

The second version is preferable because bitumen and tar with a broad range of physicochemical characteristics can be used as a raw material. Varying the bitumen to tar ratio one may obtain the initial material with the required characteristics. DST dissolves in tar within only 1–1.5 h at a lower temperature (110–130 °C), which reduces the time of polymer residence in the high-temperature zone and diminishes total time necessary for PBB preparation.

Experiments on mastering the optimal compositions of modified road bitumen were carried out. The raw material was tar with conventional viscosity of 13–35 s and bitumen with penetration equal to 70–120 mm at 25 °C. A weighed portion of the modifying agent was dissolved in tar for 1.5 h, then the resulting solution was mixed in definite proportions with the initial bitumen and analyzed using the standard procedures [9]. Unlike the procedure of PBB preparation [8] which provides the introduction of DST in the amount up to 2.5 %, the optimal concentration of DST in the modified road bitumen as determined by us is 1 mass %, which decreases the cost of the resulting PBB without worsening of its physicochemical characteristics. As a result, the modified road bitumen with the following characteristics was obtained: softening temperature, 44–50 °C; penetration at 25 °C, 90–130 mm; stretchability at 25 °C, 95–120, at 0 °C, 33–57 cm; brittle temperature, −38...−40 °C; adhesion with marble corresponds to sample No. 2.

In view of substantial diversity of the types and structures of molecules in bitumen, is seems rather problematic to predict, on the basis of bitumen composition, the properties of DST modified bitumen mixtures determining their performance characteristics. On the basis of the results obtained in our work, we developed the mathematical tool which involves the equations with the help of which it is possible to calculate the amount of tar solution of DST necessary to prepare modified road bitumen with the required characteristics on the basis of quality indices of the raw material (conventional tar viscosity, penetration of the initial bitumen) from the Samara Region:

$$\Pi_{sm} = (\Pi_b - A) + [5.84 - (0.0190VT)]C_{tar}$$

where Π_{sm} and Π_b are penetration values for the resulting PBB and the initial bitumen at 25 °C, respectively; VT is conventional tar viscosity, s; C_{tar} is concentration of tar introduced into the mixture, mass %; A is the correction factor (for bitumen with softening temperature within the ranges 40–46, 46–50 and 50–52 °C factor A is equal to 0, 20 and 40, respectively);

$$T_{sm} = T_b - [0.31 - (0.0022VT)]C_{tar}$$

where T_{sm}, T_b are softening temperatures for the resulting PBB and for the initial bitumen, °C.

Careful matching of the amounts of the polymer, bitumen and tar, correct temperature mode and shorter mixing intervals due to the use of mixing equipment with higher shearing force have a substantial effect on the basic characteristics of the resulting PBB. In order to provide even higher reliability of PBB characteristics, one may add antioxidants or use the protecting nitrogen layer during mixing. For long-term storage of PBB, one should involve as low temperature as possible and permanent mixing.

This method of obtaining PBB can be recommended for introduction at asphalt concrete plants with the use of block-module mount "Planeta" developed at the ITs Planeta JSC.

CONCLUSIONS

In comparison with the standard recommendations of SoyuzdorNII Institute, the method proposed by us allows one to decrease the amount of DST-30-01 for the preparation of modified road bitumen by a factor of 2 without any worsening of the quality. The mathematical model reported here allows us to predict the quality of the resulting modified bitumen depending on the raw material involved, and to obtain bitumen with required characteristics.

REFERENCES

1 V. A. Kretov, A. Ya. Erastov, Nauchnoye obespecheniye federal'noy programmy "Dorogi Rossii", Moscow, 1998.
2 R. S. Akhmetova, Sovremennoye sostoyaniye proizvodstva i puti povysheniya kachestva bitumov razlichnogo naznacheniya, Moscow, 1979.
3 S. V. Kotov, G. V. Timofeeva, S. V. Levanova *et al., Khim. i Tekhnol. Topliv i Masel*, 517, 3 (2003) 52.
4 J. A. N. Scott, Diskussiya po materialam–sostavlyayushchim system na osnove obychnogo bituma i bituma, modifitsirovannogo polimerami, Materialy 8 Mezhdunar. kongressa po gidroizolyatsionnym materialam, Madrid, 1992.
5 A. K. Manovyan, Tekhnologiya pererabotki prirodnykh energonositeley, Khimiya, KolosS, Moscow, 2004, p. 128.
6 Prigotovleniye smesey Karifleksa TR i bitumov. Termoplastichnye kauchuki. Tekhnicheskoye rukovodstvo TR 6.5 (R), Materialy 8 Mezhdunar. kongressa po gidroizolyatsionnym materialam, Madrid, 1992.
7 G. van Gooswilligen, V. S. Bonk, Rol' bitumov v smesyakh s termoplastichnymi kauchukami, Materialy 8 Mezhdunar. kongressa po gidroizolyatsionnym materialam, Madrid, 1992.
8 Metodicheskiye rekomendatsii po stroitel'stvu asfal'tobetonnykh pokrytiy s primeneniyem polimerno-bitumnogo vyazhushchego (na osnove DST), SoyuzdorNII, Moscow, 1975.
9 GOST 22245–90. Bitumy neftyanye dorozhnye vyazkiye. Tekhnicheskiye usloviya.