Table 2. Composition of hydrogenated Shubarkol coal

Component, wt %	Content	Test method
Organic	~60.0	State Standard GOST
Mineral	39.5	

naphthene compounds to form asphaltenes [2–6]. Hence, the role of elemental sulfur as a filler and supplementary reagent considerably affects the roadway performance of bitumen.

In the present work, we determine the physicomechanical properties and group composition of bitumen produced from Shubarkol coal. We also establish the total content of the basic components (asphaltenes, tar, and hydrocarbons).

We consider a 1 : 1 mixture of Shubarkol coal and the distillation residue (T_{bo} > 320°C) of Kumkol petroleum (Kazakhstan). The petroleum residue (a hydrogen donor) has the following characteristics: density (at 20°C) 0.8077 g/cm^3; viscosity 9.69 mm^2/s. It contains 14.73 wt % paraffins, 1.52 wt % asphaltenes, and 8.2 wt % tar, with the following elemental composition: 83.85 wt % C, 11.27 wt % H, 1.81 wt % S, 0.80 wt % N, and 2.27 wt % O.

We use a Parr 4848 batch reactor for the hydrogenation of Shubarkol coal, with upper limits of 7 MPa on the pressure and 500°C on the temperature. A mixture of tar with catalyst is heated to 70–80°C and loaded in the reactor, which has first been flushed with argon and filled with hydrogen at an initial temperature of 2–3 MPa. The working pressure and temperature are 5.0 MPa and 350–400°C, respectively; the reaction time is 5–15 min. Table 1 presents the results of tar hydrogenation. We see that the total yield of the product in the presence of molybdenum catalyst is no more than 65.1% at 400°C. For the high-temperature hydrogenation of Shubarkol coal, the optimal parameters of deep coal processing are found to be 5 MPa and 400°C.

The organic and mineral components of the hydrogenated coal are separated by continuous extraction in a Soxhlet apparatus. The solvent used is a 2 : 8 mixture of alcohol and benzene. Table 2 presents the composition of the hydrogenated derivative of Shubarkol coal.

As we see in Table 2, the organic and mineral components correspond to 60 and 39.5 wt %, respectively. The organic component is now used to produce bitumen.

We study the influence of elemental sulfur on the physicomechanical properties of bitumen in a series of experiments. The sulfur–bitumen samples are obtained by compounding: weighed portions of sulfur are heated in amounts of 10, 15, and 20 wt % with the organic component of the hydrogenated coal. A portion of sulfur is introduced in the hot sample, which is then heated to 140°C, with constant mixing in a mechanical system for 40 min.

Table 3 presents the physicomechanical properties of the samples obtained.

We find that up to 15% sulfur is optimal. Above 20%, sulfur is a structure-forming additive: it increases the viscosity, and somewhat decreases the crack resistance of the binder. Introducing sulfur in bitumen decreases the viscosity of the binder. Analysis of Table 2 indicates that, after modification with sulfur, the organic component of hydrogenated Shubarkol coal may be used as roadway bitumen, an analog of BND 60/90 bitumen. To establish the grade of the new bitumen, we determine its physicomechanical properties (Table 4).

Table 3. Physicomechanical properties of bitumen

Characteristic	Sulfur added, %		
	10	15	20
Penetration at 25°C (0.1 mm)	56	66	90
Softening temperature (ball and ring method), °C	28	48	50
Brittleness temperature (Fraass method), °C	–15	–14	11

Tests in accordance with State Standard GOST 22245–90.

Table 4. Physicomechanical properties of bitumen after adding sulfur

Brittleness temperature (Fraass method), °C	New bitumen	BND 60/90 bitumen	Test method (State Standard)
Penetration at 25°C (0.1 mm)	66	61–90	GOST 11501
Softening temperature (ball and ring method), °C	48	47–51	GOST 11506
Brittleness temperature (Fraass method), °C	–14	–15	GOST 11507
Penetration index		–1.1	GOST22245