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Rubber-modified bitumen materials for open-pit enterprises

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In the extraction of mineral resources, a leading place has belonged to open-pit mining, which is the most productive, most economic, and safest method. The scale of open-pit mining is increasing, both through an increased intensity of work at quarries and through the development of fields lying at depths of 300 m or more. As a result of this, there has been an intensification in the operation of quarry vehicles and consequently in their depreciation. Increase in the size of tipper trucks has led to an increase in the cost and intensity of tyre wear [1–3]. The accumulation of used tyres has been particularly marked in regions of north-eastern Russia and the Arctic, remote from the centres of industrial processing or recycled rubber-containing feedstock. The tyres contain rubbers, metal, and textile cord, and can, as recycled feedstock, be used in different sectors of the national economy (roadbuilding, retreading of used tyres, landscape chippings, sports and playground surfaces, reuse in the rubber industry, and so on) [4, 5]. The haulage and processing of worn tyres of vehicles used in inaccessible northern regions of Russia to developed centres of polymer feedstock processing are unprofitable.

Technology including the full cycle from tyre assembly to the production of end products is particularly promising for mining enterprises, as it will make it possible within a single mining enterprise to solve ecological problems with the utilisation of large tyres, and to produce valuable feedstock for the building of quarry roads. Furthermore, the problem of utilising used tyres within the same enterprise can be solved by the enterprise using its own internal standard documentation, in contrast to the present complexities of adopting similar measures at the municipal, regional, and federal levels.

The most large-scale means of utilising used tyres at mining enterprises is roadbuilding. It is known that the productivity of quarries depends largely on the state of their transport infrastructure. On the basis of an analysis of the structure of quarry roads [1, 2], the effectiveness of using a bitumen-based organic binder in the upper layer of road surfaces has been shown. Binders used in the surfacing of quarry roads increase the cohesion between particles of the material, fill the cavities between them, and give the rubble water-repellent properties [3].

The use of rubber crumbs as modifying additives for bitumen is acknowledged as a promising approach in roadbuilding [4–6]. The simplest method is to introduce rubber crumbs directly into bitumen, but materials produced in this way have performed poorly. Asphalt concrete produced using these binders is subject to rapid ageing and breakdown on account of the separation of rubber particles not bound strongly with the bitumen [5].

Before introduction into the bitumen, these shortcomings can be eliminated by modifying the rubber crumbs, which is necessary to form a developed interphase layer at the "rubber crumbs–bitumen" phase boundary and to increase the adhesion of the binder to the mineral components of the asphalt concrete.

In this work, natural zeolite was chosen as the modifier. In the Sakha Republic (Yakutiya) there are rich zeolite fields located in regions of intense diamond mining. The relatively low content of impurities and the high heat resistance of Yakut zeolite-bearing rock (the most exploited field, Khonguruu, yields zeolites mainly of sodium composition, and zeolites with monovalent cations are more heat resistant than zeolites with bivalent cations), combined with low cost, make natural zeolites promising modifiers for various polymeric materials.

For better mixing and activation of the modifiers of bitumen, preliminary mechanical activation of rubber crumbs together with zeolite on a planetary ball mill was carried out [7]. Mills/activators of this type ensure a very high level of energetic action on the material (the centrifugal acceleration developed by the milling bodies reaches 600 m/s^2), which ensures intense surface activation while retaining valuable elastic properties in the bulk of the rubber.

Research using optical microscopy (MBS-10 microscope) showed that, by mechanical activation, size reduction of the rubber crumbs occurs, and a reduction in the proportion of smooth areas and an increase in uneven areas of the surface are recorded, as well as separation of particles (**Figure 1**).

Investigation of the surface structure of specimens using scanning electron microscopy (JSM 6480 LV) and X-ray spectral analysis showed that, by mechanical activation, the migration of low-molecular-weight substances contained in the rubber mix (in particular, sulphur) towards the surface of the rubber crumbs occurs (**Figure 2**). Here, the specific surface of the rubber crumbs, determined on a Sorbtometer M instrument by the BET method, is practically doubled: without mechanical activation – 0.277 m^2/g, after mechanical activation for 2 min – 0.523 m^2/g, and after mechanical activation for 5 min – 0.462 m^2/g.

For asphalt concretes based on bitumens, along with the influence of the properties of the binder, features of interaction of the binder with the surface of the mineral grains are important. Therefore, in roadbed planning, the various origins of the stone materials must be taken into account.

The upper layers of the road are generally made of rubble – mineral materials produced by crushing of open-cut or mined rock. Its strength, cold resistance, and grain size are regulated by the GOST 8267-93 standard. To plan and build their own operational and other roads, it is extremely urgent for mining enterprises remote from industrial centres of regions to replace the rubble with local stone.

On the basis of recommendations of the State Road Scientific Research Institute (SoyuzdorNII), the decision was taken to develop an asphalt concrete mixture using local stone materials (a sand and gravel mixture (SGM)) obtained by quarrying. In this work, use was made of a sand and gravel mixture obtained at a diamond quarry in the Siberian Nakynsk ore field (Yakutiya) (Nyurbinsk quarry).

To substantiate the possibility of using the SGM in the composition of asphalt concrete, comparative investigations were conducted into the main characteristics of asphalt concrete specimens (**Table 1**) manufactured using the SGM and rubble, which showed that the use of the SGM as the mineral base for asphalt concrete mixtures is quite possible in the case of its use together with bitumen modified with activated rubber crumbs with zeolite. In certain characteristics (porosity, water saturation), mixtures based on an SGM are superior to analogues by 30%. This can compensate for shortcomings in other properties (porosity, tensile strength in cleavage).

For the developed composition of asphalt concrete, the grip of motor vehicle wheels with the road surface was determined. The surface was manufactured by two formulations: asphalt concretes based on bitumen without rubber crumbs and asphalt concrete based on bitumen modified with activated rubber crumbs with zeolite.

The grip was determined using an ISSP-M gauge designed for measuring this index in the building and repair of roads by periodic and day-to-day monitoring of the state of road surfaces. Investigations showed that

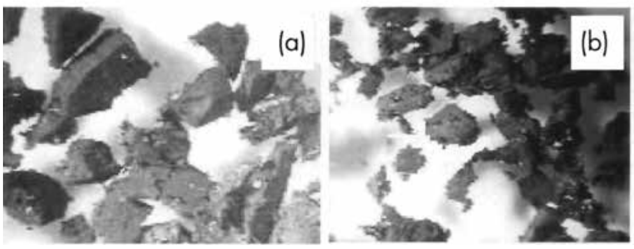

Figure 1. *The surface of rubber crumbs: (a) unactivated; (b) mechanically activated (8×)*

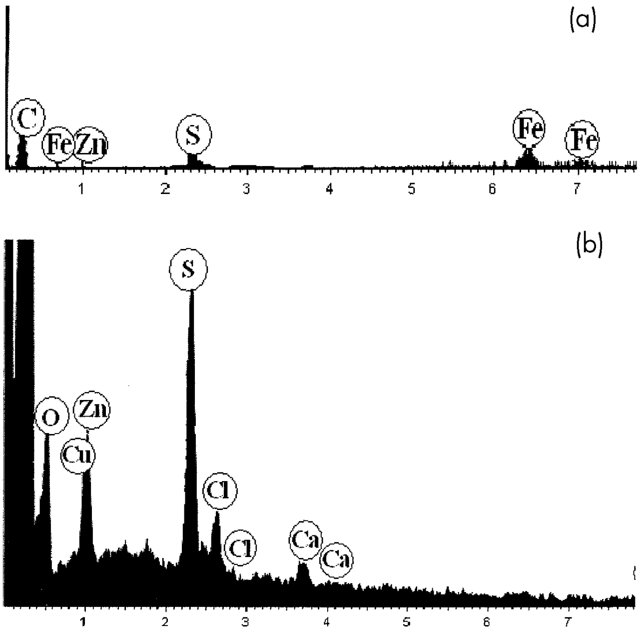

Figure 2. *Overall spectrum of distribution of elements on the surface of rubber crumbs: (a) unactivated; (b) activated. Scanning area 100 × 100 μm*

Table 1. The physicomechanical characteristics of asphalt concretes based on rubble and SGM of the Nakynsk ore field, modified with rubber crumbs and natural zeolite[a]

Asphalt concrete	ρ_m (g/cm^3)	ρ_m^m (g/cm^3)	V^m_{por} (%)	V^r_{por} (%)	W (%)	R_{comp} (MPa)	R_{cleav} (MPa)
Rubble based	2.195	2.052	13.27	7.21	1.62	5.70	3.84
Quarry SGM	2.209	2.064	21.79	16.32	1.39	5.25	1.80
Quarry SGM + (RCs + zeolite)	2.186	2.043	22.618	17.19	1.40	5.98	0.95
Quarry SGM + activated (RCs + zeolite)	2.228	2.082	19.31	15.58	1.33	6.68	1.01

[a] ρ_m – *average density of compacted material;* ρ_m^m – *average density of mineral part;* V^m_{por} – *porosity of mineral part;* V^r_{por} – *residual porosity;* W – *water saturation;* R_{comp} – *compression strength;* R_{cleav} – *tensile strength in cleavage*

grip with the road on dry and wet asphalt concrete modified with rubber crumbs was respectively 29 and 15% higher than with the base asphalt concrete.

Thus, the use of rubber-modified bitumen as a binder for roadbuilding at open-pit mines will make it possible to reduce significantly the cost of organising a high-quality transport infrastructure by using production waste (dumped barren rock and used tyres). Furthermore, the utilisation of used tyres and barren rock promotes a reduction in the adverse effect of open-pit mining on the environment and the organisation of waste-free production.

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