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Development of a standard mileage for large-sized tires under moderately severe quarry conditions

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Abstract. The tire life depends on many factors, such as the correct loading of the dump truck, longitudinal and transverse slopes of the road, turning radius, internal tire pressure, uniform distribution of the loaded ore, average operating speed of the dump truck, road surface, its condition and type, driver skill, ambient temperature, etc. It has been studied that one of the ways to increase the mileage of tires can be to reduce the number of sections, if technically possible, with longitudinal slopes of more than 8%. Based on the results of the experiment conducted at Navoi Mining and Metallurgical Combine, standard mileage of large-size Michelin tires for average operating conditions has been developed, i.e. with an average longitudinal (4%) road slope along the entire length of the transportation route and a strength factor of the mined rock of 7, according to the M.Protodyakonov scale, from which the quarry road is laid. This makes it possible to estimate the tire service life in any quarry conditions according to the developed standard mileage. Based on the test results, recommendations were developed for the rotation of large-size dump truck tires separately for the summer period and separately for other seasons, as well as recommendations for the correct use of tires.

1 Introduction

Research and development work is actively conducted around the world to address such issues as reducing transportation costs, efficient use of operating materials, and selecting trucks and tires suitable for operating conditions [1, 6, 11, 16, 19, 21]. When using large-size tires in quarries, the cost of replacing them accounts for approximately 20 – 25% of all transportation costs [2, 3, 14, 18, 22, 25, 30]. Particular attention is paid to reducing transportation costs by selecting tires that correspond to the climatic conditions of the geological zone where the quarry is located and their correct use on process and auxiliary vehicles operating in quarry conditions [4, 5, 7, 8, 10, 13, 15, 17, 20].

Currently, scientific research on the development of a methodology for predicting the service life of tires for technological (BelAZ, CAT, Komatsu, etc. with a carrying capacity of 55 to 221 tons) transport in quarry conditions is insufficiently conducted [2, 5, 23]. This is due to the fact that quarry roads are represented by permanent and temporary roads, on

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which the length of routes, longitudinal slope and route directions often change. In addition, in the summer months, an increase in the average weather temperature in Uzbekistan causes an increase in the intensity of wear or peeling of the tire tread [9, 12, 22]. As a result, the influence of the average longitudinal slope of the road along the entire length of the transportation route and the strength of the rock that formed the basis of the technological roads on the service life of large-sized tires in quarry conditions requires more in-depth research [4, 13, 14].

Based on the results of the experiment, the causes that reduce the service life of tires were identified and the research work conducted to assess them was analyzed. It was found that the process of abrasive wear of the tire tread was observed on roads paved with rock with a strength coefficient of over 8 according to the M. Protodyakonov scale [5, 8]. Three groups of factors influencing the service life of large-size tires were identified: mining and geological/geographical, operational and technological [6, 7, 13]. It was found that the greatest impact is exerted by the ambient temperature: air temperature above 40^0C leads to an increase in the actual TKPH indicator of tires, and, consequently, to premature failure of large-size tires (LST) [1, 10, 12, 23, 24, 30].

During the study, experimental research methods, methods of mathematical statistics and analysis, methods of regression analysis and Pearson linear correlation [30], and methods of constructing graphical dependencies in Microsoft Excel were used.

2 Analysis of operating conditions of technological transport

In recent years, various models of LST have been tested in operating modes in quarries of Uzbekistan with various climatic and mining-geological conditions [7, 22, 30]. Analysis of the results of LST showed that the main criterion for their performance is the heating temperature of the frame, groove and tread, which under standard operating modes of dump trucks reaches 110 – 120^0C, which leads to internal peeling of the tread [1, 3, 4, 6, 28].

Efficient use of material resources, reduction of transportation costs, as well as selection of quarry dump trucks and tires adapted to specific operating conditions have always been a pressing issue. In this regard, in the field of motor transport, it is very important to determine and control fuel consumption and tire life [2, 8, 13].

The main reasons for failure of pneumatic tires of quarry dump trucks during their operation are the following: fatigue and thermal damage (tread separation, cord delamination); natural tread wear; mechanical damage (punctures, cuts, lug chips); manufacturing defects [3, 4, 8, 10, 12, 14, 15, 27].

The Muruntau quarry depth is over 700 m, and to reduce the cost of ore transportation, a steep-inclined conveyor (SIC) is installed at level 300. The SIC currently has reduced operating hours for technical reasons. Thus, the transportation range of dump trucks increases to 14 km. This, in turn, leads to an increase in the cost of transportation. In addition, there are 2 more conveyor belts (CB) in the quarry. A crusher is installed in front of the CB. The waste rock that has passed through the crusher is transported to the dump using belts [23, 24].

In the Central Mining Administration (CMA), the Automobile Transport Administration (ATA) includes 224 dump trucks and 155 units of auxiliary transport and road construction equipment. These vehicles are used in 4 quarries (Muruntau, Amantai, Balpantau and Turbai) [24, 29, 30].

ATA directly services the Muruntau quarry. The Muruntau quarry is serviced by 117 quarry dump trucks, 65 auxiliary vehicles and road construction machines (RCM, 21 units).

Load control system: the BelAZ-7513 dump trucks are equipped with the Load and fuel control system (LFCS), the CAT-789 with the VIMS system, and the Komatsu HD785-7 was recorded from the parameters of the pressure sensors on the vehicle suspension cylinders (all 4 sensors) [6, 27, 30].

3 Experiment

Based on the analysis of 10 studied routes, the following was revealed. If we take the total length of the routes equal to 100%, then about 60% correspond to the passport of the Muruntau quarry road, i.e. the slope on the route is from -2 to +10%. The longitudinal slope of the remaining 40% of the road fluctuates from 10 to 17%, on average 15% (Fig. 1). Roads with an average longitudinal slope of 15% lead to accelerated wear of the rear axle tires, reduce the service life of dump truck units and assemblies, and contribute to an increase in the spillage of rock mass from the dump truck bodies.

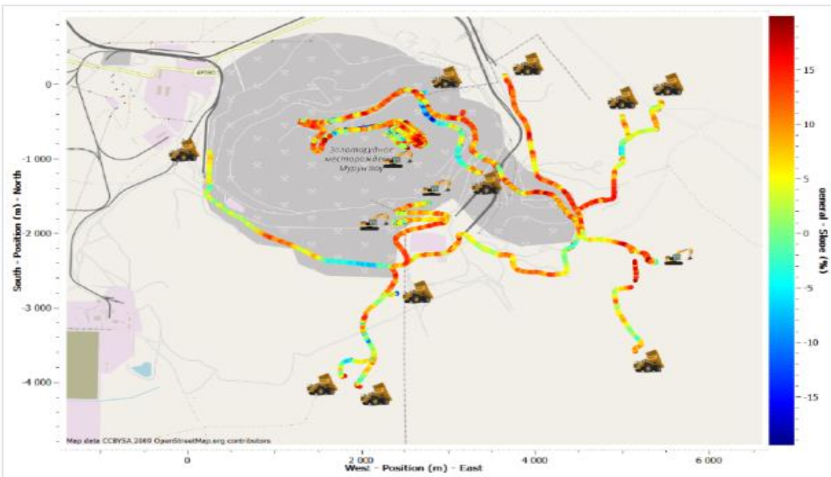

Fig. 1. Studied routes using the V-BOX device

Research to determine the influence of ambient temperature on the intensity of tire wear was conducted in the Muruntau quarry of Navoi Mining and Metallurgical Company JSC.

For this purpose, qualified drivers and 5 CAT-793D dump trucks manufactured in 2019 – 2021 were selected. On November 30, 2022, 30 new 40.00R57 MICHELIN XDR3 MB TL E4R tires were installed on the dump trucks. The tread depth of these tires was 98 mm, the load index was 60.000 kg, the speed index was 50 km/h, the recommended tire pressure was 650 kPa, and the TKPH was 960. The CAT-793D dump trucks had a lifting capacity of 220 tons [30].

Based on the results of the experiments, graphs (Fig. 2) and a diagram (Fig. 3) were constructed.

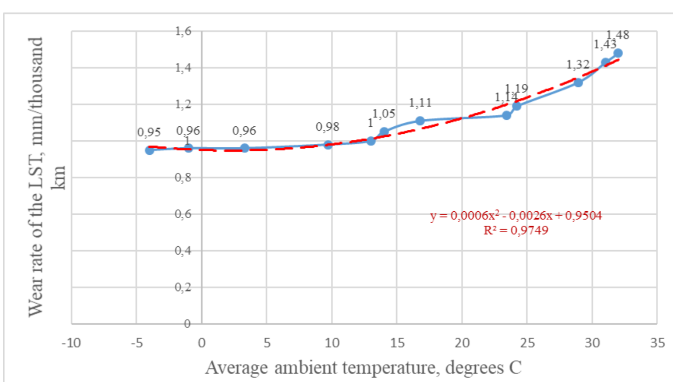

Fig. 2. The influence of ambient temperature on tire wear rate

Based on the results of the experiment conducted in the Muruntau quarry, a graph of the intensity of tire tread wear was constructed, corresponding to the average air temperature in each month [28].

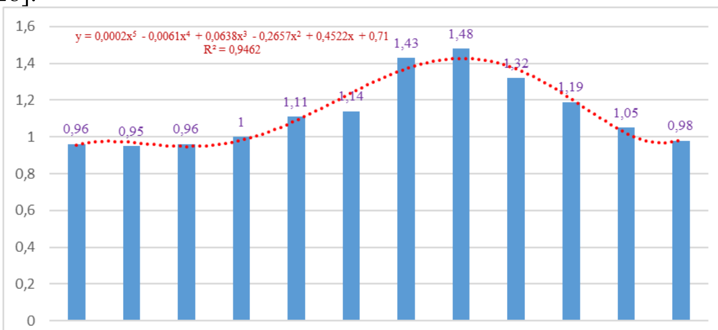

Fig. 3. Tire wear intensity by month

Experimental work on the effect of the average longitudinal slope of the transportation distance on the tire service life was carried out at the Muruntau quarry. The experiments were carried out on BelAZ-75310 dump trucks, the largest number of which at the quarry - 46 units. For the experiment, 20 dump trucks with good technical condition and drivers with at least 10 years of experience were selected, divided into 5 groups [27, 28, 30].

Table 1. Results of the experiment conducted on controlled dump trucks BelAZ-75310 (40.00R57, Michelin XDR3) at the Muruntau quarry

№ groups	Garage number of dump trucks	Average transportation distance L, m	Average transportation height H, m	Average slope H/L, %	Average mileage of LST, km
1	455, 459, 505, 151	3182	68.1	2.14	77493
2	150, 452, 508, 520	4680	141.8	3.03	71918
3	503, 156, 353, 352	5002	206.1	4.12	68625
4	509, 510, 458, 157	4947	264.2	5.34	65018
5	159, 355, 160, 519	4875	305.7	6.27	60225

Based on the results of the experiment (Table 1), a graph was constructed assessing the influence of the average longitudinal slope of the transportation distance on the service life of tires (Fig. 4).

Since longitudinal slopes from 0 to 8% are optimal for quarry dump trucks, an average 4% slope per transportation distance was taken as the norm. Thus, if the average longitudinal slope of the routes is 4%, there is no effect on the tire life, i.e. $K_\alpha = 1$.

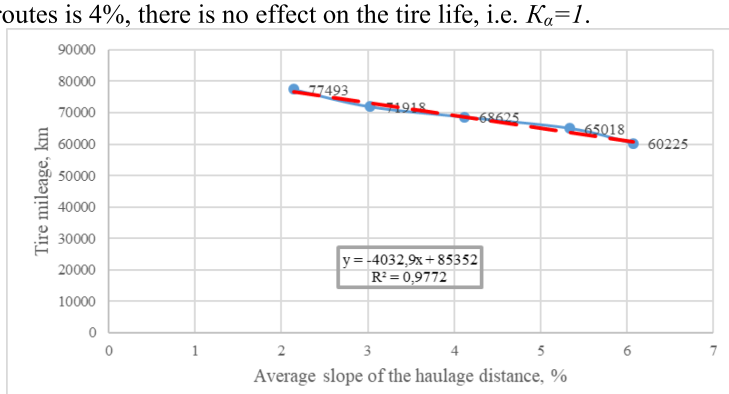

Fig. 4. The influence of the average slope of the transportation distance on the tire service life

In the Muruntau quarry, the strength of the rock averaged 11 on the M. Protodyakonov scale. For operating conditions, the following relationship was established between the tire mileage and the average slope of the transportation distance (look at Fig. 4):

$$y = -4032.9x + 85352 \tag{1}$$

Based on the use of this linear function, the tire mileage corresponding to each value of the average slope of the haulage distance was predicted (Table 2).

Table 2. Predicting the life of large-size tires depending on the average slope of the transportation distance

Average slope of the haulage distance, %	0	1	2	3	**4**	5	6	7	8	9	10
Average mileage of LST, km	85352	81319	77286	73253	**69220**	65187	61154	57121	53088	49056	45023

The average longitudinal (4%) slope of the road along the entire length of the transportation route is optimal for quarry dump trucks. Therefore, the effect of the average slope of the transportation distance of 4% on the tire service life was taken to be equal to one. As a result, a linear dependence was created showing the effect of the average longitudinal slope of the transportation distance on the tire service life (Fig. 5).

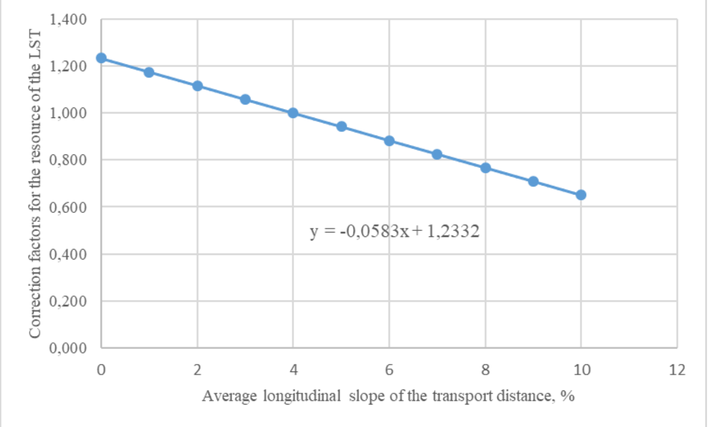

Fig. 5. The influence of the average slope of the transportation distance on the service life of large-size tires

From the graph in Fig. 5 it is evident that an increase in the average slope of the transportation distance by 1% leads to a decrease in the tire service life by 5.83%, and vice versa, a decrease by 1% increases the tire service life by 5.83%. From the graph one can find the correction factors reflecting the influence of the average slope of the transportation distance on the service life of large-size tires, according to the following formula [30]:

$$K_\alpha = -0.0583 \cdot \alpha + 1.2332 \,. \tag{2}$$

According to formula (2), through forecasting, the correction factors for the tire life (K_α) are found, corresponding to each percentage of the longitudinal slope of the transportation distance (Table 3) [23].

Table 3. Determination of tire life correction factors

Average slope of the haulage distance, %	**Estimated tire mileage, km**	**Tyre life correction factors, K_α**
0	85352	1.233
1	81319	1.175
2	77286	1.116
3	73253	1.058
4	**69220**	**1**
5	65187	0.942
6	61154	0.883
7	57121	0.825
8	53088	0.767
9	49056	0.709
10	45023	0.650

Assessing the impact of the strength of the rock that forms the basis of quarry roads on the service life of large-size tires. A study of quarry operating conditions and an analysis of the mileage of written-off tires showed that one of the main factors is the strength of the rock that forms the basis of quarry roads.

In the quarries of Amantai, Rokhat, Davgyztau, Kokpatas, Turbai and Daikovy, which belong to Navoi Mining and Metallurgical Combine, the rock strength coefficient is different (4.6 ÷ 14). BelAZ-7555B, CAT-773E and Komatsu HD-465-7 dump trucks (with tire size 24.00R35) are used in these quarries. The study revealed that BelAZ-7555V dump trucks are used in all 5 previously listed quarries.

Table 4. Results of the study of the influence of the strength of the rock that formed the basis of quarry roads on the service life of large-size tires

Quarries	**Garage numbers of the dump trucks that took part in the experiment**	**Average transportation distance L, м**	**Average height of transportation H, м**	**Average longitudinal slope H/L, %**	**Strength of the mined rock**	**Average strength of the breed**	**Average tire mileage, km**
Amantai	600, 617, 619, 611	1650	43.74	2.65	4.6 – 9,39	7	95323
Davgystau	311, 317, 318, 345	1800	59.94	3.33	4 – 14	9	81670
Rohat	250, 291, 342, 343	1350	42	3.1	5 – 15	10	78050
Kokpatas	620, 621, 624, 625	1920	65.4	3.41	8 – 14	11	77504
Daikovy	221, 222, 233, 234	947	28.6	3.02	10.7 – 14	12,35	74400

According to the degree of strength of the extracted rock, the Amantai quarry (on average - 7) belongs to medium-heavy operating conditions. According to the analysis of the mileage of 82 tires written off at this quarry in 2022, the average mileage was 100.200 km.

Taking into account the standard mileage of tires for medium-severity quarry conditions and the factors influencing the service life of tires, for each quarry the following empirical formula can be written for the average actual mileage of dump trucks in each group:

$$L_{fact} = S_n \cdot K_\alpha \cdot K_{kp} \cdot K_{TKPH}. \quad (3)$$

Here S_H is the standard mileage of tires for medium-heavy quarry conditions, km; K_α is the correction factor assessing the effect of the average longitudinal slope of the transportation distance on the tire service life; $K_{кр}$ is the correction factor assessing the effect of the strength of the rock that forms the basis of quarry roads on the tire service life; K_{TKPH} is the correction factor assessing the effect of each percentage change in the actual TKPH indicator of large-size tires compared to the nominal one on the tire service life.

Having calculated the results of experiments conducted at five quarries with different levels of hardness (see Table 4) and using formula (3), we find the correction factors for the resource of large-sized tires corresponding to the average slopes of the transportation distance (Table 5).

As can be seen from Table 5, all the coefficients found are greater than 1, since, as the dissertation author assumed, the influence of an average slope of 4% on the tire service life is equal to 1.

Table 5. Correction factors for tire life corresponding to the average slope of the haulage distance in quarries with different rock strengths

Quarries	**Average slope over the haul distance α, [%]**	**Tyre life adjustment factors, K_α**
Amantai	2.65	1.076
Davgystau	3.33	1.05
Rohat	3.1	1.037
Kokpatas	3.41	1.033
Daikovy	3.02	1.054

Using the experimental results presented in Table 4, formula (3) and Table 5, we find the correction factors that evaluate the influence of the strength of the rock that is the basis of quarry roads on the service life of tires:

1. In the Amantai quarry:

$$95323 = S_n \cdot 1.076 \cdot К_{kр7} \cdot К_{TKPH}\,, \qquad (4)$$

$$K_{kр7} = \frac{95323}{S_n \cdot 1.076 \cdot K_{TKPH}}\,. \qquad (5)$$

2. In the Davgyztau quarry:

$$81670 = S_n \cdot 1.037 \cdot К_{kр9} \cdot К_{TKPH}\,, \qquad (6)$$

$$K_{kр9} = \frac{81670}{S_n \cdot 1.037 \cdot K_{TKPH}}\,. \qquad (7)$$

3. In the Rohat quarry:

$$78050 = S_n \cdot 1.05 \cdot К_{кр10} \cdot К_{TKPH}\,, \qquad (8)$$

$$K_{kр10} = \frac{78050}{S_n \cdot 1.05 \cdot K_{TKPH}}\,. \qquad (9)$$

4. In the Kokpatas quarry:

$$77504 = S_n \cdot 1.033 \cdot К_{kр11} \cdot К_{TKPH}\,, \qquad (10)$$

$$K_{kр11} = \frac{77504}{S_n \cdot 1.033 \cdot K_{TKPH}}\,. \qquad (11)$$

5. In the quarry Daikovy:

$$74400 = S_n \cdot 1.054 \cdot \text{К}_{k\text{р}12} \cdot \text{К}_{TKPH}\,, \tag{12}$$

$$K_{k\text{р}12} = \frac{74400}{S_n \cdot 1.054 \cdot K_{TKPH}}\,. \tag{13}$$

Considering that all manufacturers of LST produce tires for different quarry operating conditions, the dissertation author accepted that the average rock strength is 7 on average and its effect on the tire life is 1, i.e.

$$K_{kp7}=1\,. \tag{14}$$

During the experiments, it was checked that the actual TKPH value of the tires did not exceed the nominal value, and its influence on the tire life was taken as $K_{TKPH} = 1$. Since the model of the tested tires is the same, the standard mileage ($S_\text{н}$) is also the same.

As a result, from the relationship of formula (7) to formula (5) for a quarry with an average rock strength of 9 according to the M. Protodyakonov scale, mined in quarries, the tire resource correction factor is found as follows:

$$\frac{\text{К}_{k\text{р}9}}{\text{К}_{\text{кр}7}} = \frac{\frac{81670}{S_n \cdot 1.037 \cdot K_{TKPH}}}{\frac{95323}{S_n \cdot 1.076 \cdot K_{TKPH}}} = \frac{81670 \cdot 1.076}{95323 \cdot 1.037} = 0.889\,, \tag{15}$$

$$K_{k\text{р}9} = 0.889 \cdot \text{К}_{k\text{р}7} = 0.889\,. \tag{16}$$

For a quarry with an average rock strength of 10, from the ratio of formula (9) to formula (5):

$$\frac{\text{К}_{k\text{р}10}}{\text{К}_{k\text{р}7}} = \frac{\frac{78050}{S_n \cdot 1.05 \cdot K_{TKPH}}}{\frac{95323}{S_n \cdot 1.076 \cdot K_{TKPH}}} = \frac{78050 \cdot 1.076}{95323 \cdot 1.05} = 0.839\,, \tag{17}$$

$$K_{k\text{р}10} = 0.839 \cdot \text{К}_{k\text{р}7} = 0.839\,. \tag{18}$$

For a quarry with an average rock hardness of 11, from the ratio of formula (11) to formula (5):

$$\frac{\text{К}_{k\text{р}11}}{\text{К}_{k\text{р}7}} = \frac{\frac{77504}{S_n \cdot 1.033 \cdot K_{TKPH}}}{\frac{95323}{S_{\text{н}n} \cdot 1.076 \cdot K_{TKPH}}} = \frac{77504 \cdot 1.076}{95323 \cdot 1.033} = 0.813\,, \tag{19}$$

$$K_{k\text{р}11} = 0.813 \cdot \text{К}_{k\text{р}7} = 0.813\,. \tag{20}$$

For a quarry with an average rock hardness of 12.35, from the ratio of formula (13) to formula (5):

$$\frac{\text{К}_{k\text{р}12}}{\text{К}_{k\text{р}7}} = \frac{\frac{74400}{S_n \cdot 1.054 \cdot K_{TKPH}}}{\frac{95323}{S_n \cdot 1.076 \cdot K_{TKPH}}} = \frac{74400 \cdot 1.076}{95323 \cdot 1.054} = 0.779\,, \tag{21}$$

$$K_{\text{кр}12} = 0.779 \cdot \text{К}_{k\text{р}7} = 0.779\,. \tag{22}$$

The following graph (Fig. 6) was created based on the results of experiments (formulas 14, 16, 18, 20, 22) conducted in quarries with different degrees of rock hardness and using actual tire mileage. The graph is based on the average tire mileage of dump trucks participating in the experiments conducted in quarries with different rock hardness.

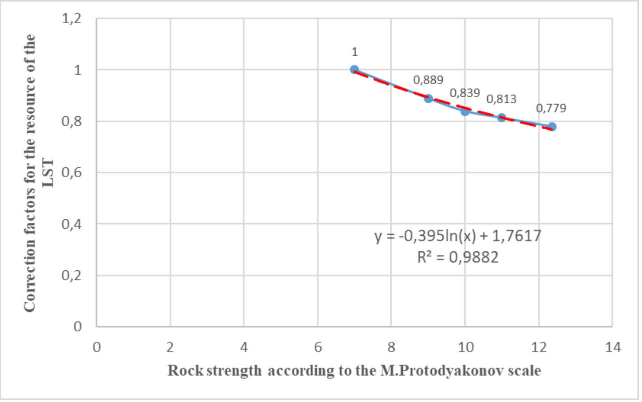

Fig. 6. The influence of different rock strength on the service life of LST

Using the logarithmic dependence created on the graph (see Fig. 6), the forecasting method was used to calculate the correction factors affecting the resource of the LST corresponding to each rock strength (Fig. 7). As can be seen, if the average rock strength laid on quarry roads is less than 7, the tire resource increases, and vice versa.

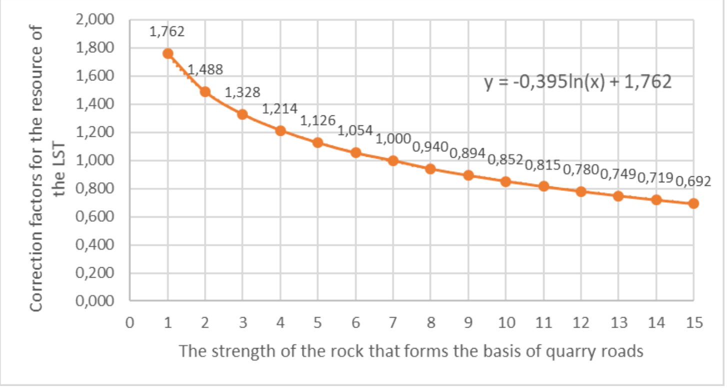

Fig. 7. The influence of the strength of the rock that forms the basis of quarry roads on the service life of LST

According to the graphical analysis, the correction factor for the resource of large-size tires, taking into account the influence of the strength of the rock laid on quarry roads, is found using the following logarithmic formula:

$$K_{kp} = -0.395 \cdot ln(k) + 1.762. \quad (23)$$

Here, k is the coefficient of rock strength according to the M. Protodyakonov scale, which forms the basis of quarry roads.

Based on the results of the experiment, a standard mileage of large-size Michelin tires (40.00R57 XDR3 MB, 33.00R51 XDR3 MB, 27.00R49 XDR3 MB and 24.00R35 XTRA Load Grip MB) was developed for average operating conditions, i.e. with an average 4% slope of the transportation distance and an average rock strength of 7, from which the quarry road is laid [30].

Based on the results of experiments conducted to study the influence of the average longitudinal (4%) slope of the road along the entire length of the transportation route and the degree of strength of the rock that formed the basis of quarry roads on the resource of the

LST, we will determine the standard mileage of dump trucks in each group, according to the formula (3):

$$S_n = \frac{L_{fact}}{K_\alpha \cdot K_{kp} \cdot K_{TKPH}} = \frac{L_{fact}}{(-0.0583 \cdot \alpha + 1.2332) \cdot (-0.395 \cdot ln\,(x) + 1.762) \cdot 1} \quad (24)$$

For each Michelin tire model, the experimental results were entered into formula (24) and the standard mileage for medium-severity quarry conditions was calculated.

For tire models 40.00R57 XDR3 MB:

$$S_{n1} = \frac{77493}{(-0.0583 \cdot 2.14 + 1.2332) \cdot (-0.395 \cdot ln\,(11) + 1.762)} = 85800\ km; \quad (25)$$

- for tire models 33.00R51 XDR3 MB, $S_n = 85200\ km$;
- for tire models 27.00R49 XDR3 MB, $n = 82300\ km$;
- for tire models 24.00R35 XTRA Load Grip MB, $S_n = 87400\ km$.

The experiments started in September and ended in May, taking into account that the main factor causing the increase in the actual TKPH value of large-size tires is high ambient temperature. Thanks to this, it was controlled that the actual TKPH value of tires was within the normal range.

4 Conclusions

The influence of ambient temperature on the wear rate of industrial transport tires in the conditions of the sharply continental climate of Uzbekistan was studied. The lowest tire wear rate was found in January – 0.95 and the highest in July – 1.48. Cool weather from October to April (up to 20^0C) compensated for tire overheating and did not cause thermal delamination.

In the Muruntau quarry, the dump truck operates with high productivity, so it is recommended to use tires with the MB rubber compound (Michelin 40.00R57 XDR3+ MB E4R TL). The TKPH of each cycle depends on the speed of the dump truck, the average load on the tires and the ambient temperature. The average load on the tire, in turn, depends on the longitudinal slope of the transportation distance.

It has been substantiated that one of the ways to increase the mileage of tires may be to reduce the number of sections, if technically possible, with longitudinal slopes of more than 8%. It is noted that a decrease in the average slope of the transportation distance by 1% leads to an increase in the tire life by 5.83%, and vice versa.

Based on the test results, recommendations for the rotation of large-size tires of technological transport were developed and tested separately for the summer period and separately for other seasons, and recommendations for the correct use of tires were developed. As a result, the resource of tires dump truck increased by 7%.

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