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RESEARCH ARTICLE

# THE EFFECT OF VEHICLE SPEED ON THE REDUCTION OF PAVEMENT SKID RESISTANCE UNDER WINTER SLIPPERY CONDITIONS

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**Abstract.** *This article examines the factors influencing the reduction of tire–road adhesion under winter conditions, with particular emphasis on vehicle speed, snow and ice formations, and pavement surface characteristics. The study aims to determine how vehicle speed and pavement macrotexture affect the coefficient of adhesion on winter road surfaces. Computational methods were applied to establish the relationship between vehicle speed and the coefficient of adhesion. The analysis considered different types of snow and ice formations, as well as the influence of crushed stone size and shape on pavement texture and macro-roughness. The findings indicate that as vehicle speed increases, the coefficient of adhesion decreases, especially on surfaces affected by icing or snow accumulation. This reduction is associated with shorter tire–road contact time and increased dynamic loads, which weaken tread interaction with surface irregularities. The study also confirms that the size and shape of mineral aggregates significantly influence pavement macro-roughness. Higher macro-roughness improves drainage capacity, reducing water accumulation and the likelihood of ice formation. However, excessive crushed stone content may accelerate pavement wear and lead to partial deterioration of the surface layer, negatively affecting adhesion. Additionally, surface depressions can accumulate moisture that freezes at subzero temperatures, forming initial icing zones that expand under traffic loads. Vehicle speed and pavement macrotexture are critical factors affecting skid resistance in winter conditions. Proper selection of aggregate characteristics and effective winter maintenance strategies are essential to minimize slipperiness and enhance road safety.*

**Keywords:** *road and climatic conditions, snow and ice formation, snow rolling, snow mechanics, speed of movement, surface roughness.*

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ҒЫЛЫМИ МАҚАЛА

# ҚЫСҚЫ ТАЙҒАҚ ЖАҒДАЙЫНДА КӨЛІК ҚҰРАЛДАРЫНЫҢ ҚОЗҒАЛЫС ЖЫЛДАМДЫҒЫНЫҢ ЖОЛ ЖАБЫНДАРЫНЫҢ ІЛІНІСУ ҚАСИЕТТЕРІНІҢ ТӨМЕНДЕУІНЕ ӘСЕРІ

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**Аңдатпа.** *Бұл мақалада қыс мезгілінде автомобиль шиналарының жол төсемімен байланысу коэффициентінің төмендеуіне әсер ететін негізгі аспектілер қарастырылады. Қар-мұз түзілімдерінің әртүрлі түрлерінің, сондай-ақ көлік құралдарының қозғалыс жылдамдығының ілінісу сипаттамаларына әсеріне ерекше назар аударылады.Есептеу әдістерінің көмегімен мақалада ілінісу коэффициенті мен көлік құралының жылдамдығы арасындағы байланыс орнатылған. Жылдамдықтың жоғарылауымен ілінісу коэффициентінің төмендеу тенденциясы байқалады, әсіресе мұздануға немесе қардың пайда болуына бейім жабындарда. Бұл шинаның жол бетімен жанасу уақытының азаюына және протектордың жабынның кедір-бұдырымен әрекеттесу тиімділігін төмендететін динамикалық жүктемелердің өсуіне байланысты. Зерттеу жол жамылғысының құрамында қолданылатын қиыршық тастың мөлшеріне ерекше назар аударады. Минералды материал дәндерінің мөлшері мен пішіні жол бетінің құрылымы мен макро кедір-бұдырына тікелей әсер ететіні анықталды. Макро кедір-бұдырлық неғұрлым жоғары болса, жабынның дренаждық қасиеттері соғұрлым жақсы болады, бұл судың жиналуын болдырмайды және сәйкесінше мұздың немесе қардың пайда болу мүмкіндігін азайтады. Сонымен қатар, тым үлкен қиыршық тас жабынның тез тозуына және жоғарғы қабат құрылымының ішінара бұзылуымен байланыс қасиеттерінің нашарлауына әкелуі мүмкін. Мақалада сонымен қатар макро кедір-бұдырдың беткі ылғалдың жиналуына ықпал ететін факторлардың бірі ретіндегі рөлі, әсіресе жабынның төмендеуінде талданады. Бұл ылғал аязды жағдайда қатып, мұзданудың бастапқы аймақтарын құрайды, содан кейін олар көлік ағынының әсерінен көбейеді. Мұндай учаскелер тайғақтықтың жоғарылауының ошағына айналады, бұл жол төсемдерін жобалау, күтіп ұстау және қысқы өңдеу кезінде тиісті шараларды қабылдауды талап етеді.*

**Түйін сөздер:** *жол-климаттық жағдайлар, қар-мұздың пайда болуы, қардың оралуы, қар механикасы, қозғалыс жылдамдығы, жабындардың кедір-бұдырлығы.*

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НАУЧНАЯ СТАТЬЯ

# ВЛИЯНИЕ СКОРОСТИ ДВИЖЕНИЯ ТРАНСПОРТНЫХ СРЕДСТВ НА СНИЖЕНИЕ СЦЕПНЫХ КАЧЕСТВ ДОРОЖНЫХ ПОКРЫТИЙ В УСЛОВИЯХ ЗИМНЕЙ СКОЛЬЗКОСТИ

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**Аннотация.** *В данной статье рассматриваются ключевые аспекты, влияющие на снижение коэффициента сцепления автомобильных шин с дорожным покрытием в зимних условиях. Особое внимание уделяется влиянию различных типов снежно-ледяных образований, а также скорости движения транспортных средств на характеристики сцепления. С помощью расчетных методов в статье установлена зависимость между коэффициентом сцепления и скоростью движения транспортного средства. Установлено, что при увеличении скорости наблюдается тенденция к снижению коэффициента сцепления, особенно на покрытиях, подверженных обледенению или образованию снежного наката. Это объясняется уменьшением времени контакта шины с поверхностью дороги и ростом динамических нагрузок, которые снижают эффективность взаимодействия протектора с шероховатостью покрытия. Отдельное внимание в исследовании уделено размеру щебня, используемого в составе дорожного покрытия. Установлено, что крупность и форма зерен минерального материала напрямую влияют на текстуру и макрошероховатость дорожной поверхности. Чем выше макрошероховатость – тем лучше дренажные свойства покрытия, что препятствует скоплению воды и, соответственно, снижает вероятность образования льда или снежного наката. В то же время, слишком крупный щебень может приводить к быстрому износу покрытия и ухудшению сцепных качеств при частичном разрушении структуры верхнего слоя. В статье также проанализирована роль макрошероховатости как одного из факторов, способствующих накоплению поверхностной влаги, особенно в понижениях местах покрытия. Эта влага в условиях отрицательных температур замерзает, образуя начальные участки обледенения, которые затем увеличиваются под действием транспортного потока. Такие участки становятся очагами повышенной скользкости, что требует принятия соответствующих мер при проектировании, содержании и зимней обработке дорожных покрытий.*

**Ключевые слова:** *дорожно-климатические условия, снежно-ледяное образование, снежный накат, механика снега, скорость движения, шероховатости покрытий.*

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**CONFLICT OF INTEREST**

The authors state that there is no conflict of interest.

During the preparation of this manuscript, the authors used artificial intelligence tools (ChatGPT) solely for editorial assistance, such as improving phrasing and checking grammar, spelling, and punctuation. All ideas, interpretations, and conclusions are the responsibility of the authors, who take full accountability for the content of the article.

**АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ**

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

**МҮДДЕЛЕР ҚАҚТЫҒЫСЫ**

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Мақаланы дайындау барысында авторлар жасанды интеллект құралдарын (ChatGPT) тек редакциялық көмек мақсатында пайдаланды: тұжырымдарды жетілдіру, грамматикалық, орфографиялық және тыныс белгілеріндегі қателерді тексеру үшін. Барлық идеялар, интерпретациялар мен қорытындылар авторларға тиесілі, және олар мақаланың мазмұнына толық жауапты.

**БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ**

Исследование проводилось с использованием частных источников финансирования

**КОНФЛИКТ ИНТЕРЕСОВ**

Авторы заявляют, что конфликта интересов нет.

При подготовке рукописи авторы использовали инструменты искусственного интеллекта (ChatGPT) исключительно для редакторской поддержки: корректировки формулировок, проверки грамматических, орфографических и пунктуационных ошибок. Все идеи, интерпретации и выводы принадлежат авторам, которые несут полную ответственность за содержание статьи.

## 1 INTRODUCTION

The aim of this study is to identify the factors affecting the reduction of tire-road friction in winter conditions and to determine the relationship between the friction coefficient, vehicle speed, and pavement characteristics. This task is addressed in the field using the PKRS-2U dynamometric trailer, which was employed to measure the friction coefficient on various types of road surfaces.

An analysis of both international and domestic research shows that one of the main causes of road traffic accidents (RTAs) on federal highways – as well as on republican roads in CIS countries – is the impact of accompanying road conditions, namely climatic factors. However, despite the overall increase in the number of RTAs, since 2023 there has been a decrease in accidents caused by adverse road conditions on republican roads in Kazakhstan. For instance, while the number of such accidents reached 325 cases in 2011, by 2022 this figure had decreased to 214, a 1.5-fold reduction. This trend is associated with the region's climatic conditions and the operational and technical characteristics of the road infrastructure. The key factor influencing accident rates in this context is the pavement surface friction coefficient.

On January 3 at 13:28, a massive traffic accident involving 95 vehicles occurred simultaneously at the 104th kilometer of the Astana–Shchuchinsk highway, near the village of Zhanatalap (**Figure 1a**). According to the Road Police, the cause of the accident was drivers' failure to comply with traffic regulations – specifically, excessive speed and insufficient safe following distance. However, drivers expressed a different opinion, placing the blame on the road maintenance services. Regardless of these differing perspectives, in practice, during snow removal operations on highways, the outer edges of the roadway are often not fully cleared of snow. As a result, the remaining snow is easily compacted by vehicle tires into a snow-ice layer (**Figure 1b**), with a surface friction coefficient dropping to 0.1 or even lower.

a)

b)

**Figure 1.** Large-scale traffic accident at km 104 of the Astana–Shchuchinsk highway (a); snow-ice layer remaining uncleared from the edge of the roadway (b) **(Automotive News, 2025).**

As a result of this large-scale vehicle collision, road operator KazAvtoZhol reported that traffic on this section was suspended from 13:28 until 23:50. According to the requirements of **ST RK 1279-2013 and PR RK 218-27-2014,** the maintenance quality of such a road section is classified as hazardous.

The issues of ensuring adequate tire-road friction in winter conditions have been extensively studied both in the CIS countries and abroad. Significant differences in approaches between countries are determined by regional climatic conditions, traffic intensity, and the standards applied for winter road maintenance. **(Lobanov, 2019)**

In countries with prolonged winter periods, primary attention is given to experimental studies of the tire-road friction coefficient on various types of snow and ice formations. Field measurements are widely conducted using specialized towed devices and friction measurement instruments.

Several studies also examine the influence of pavement macrotexture and the effectiveness of anti-icing materials. **(Kingeri, et al.,1996, Titova, 2015)**

The speed of vehicles on a roadway is one of the key indicators of its user performance characteristics and a major factor influencing road traffic safety. **(Chvanov, 2011)** Methods for ensuring traffic safety during the design of new roads, their reconstruction, repair, and maintenance of existing infrastructure are widely studied, with particular attention given to the role of traffic management measures in improving road safety **(Babkov et al., 1978)**.

Combined approaches to assessing the transport-operational condition of roads include evaluation of the route based on key technical parameters and characteristics **(Kuznetsov, 2022)**. The technical level and operational condition of a road must comply with regulatory standards and ensure all necessary conditions for accident-free traffic situations **(Kurakina, 2014).**

Based on the analysis of a large dataset of measured vehicle speeds and road accident statistics, it was found that the lowest risk of traffic accidents occurs within the speed range of 85–90% of the maximum permitted speed. This range represents the safest speed for traffic flow and has been adopted in modern standards as the design speed for determining the values of geometric road elements **(Kiyalbaev et al., 2023, Kutela et al., 2025).**

## 2 MATERIALS AND METHODS

The study utilized data from field measurements of the tire-road friction coefficient on various types of snow and ice formations along the Kostanay–Surgan highway (km 40–82 and km 89–103). Based on these field measurements, calculation methods were also applied, relying on the analysis of well-established theoretical relationships describing the interaction between the tire and the road surface.

Influence of pavement friction coefficient on vehicle speed. On dry and clean pavement surfaces, at a vehicle speed of 60 km/h, the friction coefficient on straight road sections ranges from 0.65 to 0.70 (the friction coefficient was measured under field conditions using a PKRS-2U dynamometric trailer). As the vehicle speed increases from 60 to 80 km/h, the friction coefficient decreases by approximately 0.05 to 0.10. According to **(Kuznetsov 2022, De Vos et al., 2023)** the minimum permissible friction coefficient during road operation – including for stopping lanes – must not fall below 0.4 at a speed of V = 60 km/h on wet pavement, across the full width of the carriageway.

The roughness and condition of the roadway surface must ensure an adequate level of tire-to-pavement adhesion, which is characterized by the friction coefficient**.** The friction coefficient must be ≥ 0.3 when measured with a smooth (treadless) tire and ≥ 0.4 when measured with a tire having a tread pattern. **(Yesbolat et al., 2025)**

The indicator of pavement grip and surface roughness – known as the relative friction coefficient (or slip coefficient**)** – is calculated as the ratio of the actual measured friction coefficient ($\varphi_f$) to its permissible value ($\varphi_p$) **(Melnikov, 1974)**:

$$K_c = \frac{\varphi_f}{\varphi_p} \geq 1 \tag{1}$$

where:
$K_c$ - slip coefficient;
$\varphi_f$ - actual friction coefficient;
$\varphi_p$ -permissible (minimum required) friction coefficient.

The friction coefficient depends on the type and condition of the pavement, tire type and construction, tread pattern, pavement wear, vehicle speed, wheel load, temperature, and other factors **(Figure 2, Table 1)**.

The most significant influences are the pavement type and condition, as well as vehicle speed. Therefore, for an objective assessment of road conditions, the friction coefficient should be measured at a standardized speed of 60 km/h in each case. Tabulated friction coefficient values should only be used for approximate calculations.

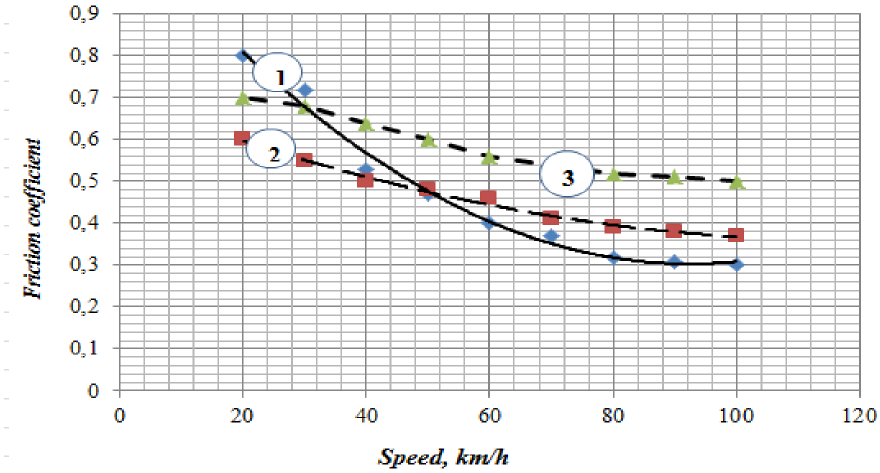



**Figure 2 –** Dependence of the friction coefficient on vehicle speed for pavements with different roughness:
1 – sand asphalt concrete; 2 – dense-graded asphalt concrete;
3 – surface treatment (author's materials)

**Table 1**
Values of friction coefficients and friction adjustment factors (author's materials)

| Pavement | Pavement condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reference (dry) coating | | Wet (clean) | | Wet (dirty) | | Loose snow | | Compacted snow | | Ice | |
| | $\varphi_n$ | $b_\varphi$ | $\varphi_n$ | $b_\varphi$ | $\varphi_n$ | $b_\varphi$ | $\varphi_n$ | $b_\varphi$ | $\varphi_n$ | $b_\varphi$ | $\varphi_n$ | $b_\varphi$ |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Cement concrete | 0.80-0.85 | 0.002 | 0.65-0.70 | 0.0035 | 0.40-0.45 | 0.0025 | 0.15-0.35 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.08-0.15 | 0.002 |
| Asphalt concrete with surface texturing | 0.80-0.85 | 0.0035 | 0.60-0,65 | 0.0035 | 0.45-0.55 | 0.0035 | 0.15-0.35 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.10-0.20 | 0.002 |
| Hot-mix asphalt concrete without surface texturing | 0.80-0.85 | 0.002 | 0.50-0.60 | 0.0035 | 0.35-0.40 | 0.0025 | 0.15-0.35 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.08-0.15 | 0.002 |
| Cold mix asphalt | 0.60-0.70 | 0.005 | 0.40-0.50 | 0.004 | 0.30-0.35 | 0.0025 | 0.12-0.30 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.08-0.15 | 0.002 |
| Black crushed stone and black gravel surfaces with surface texturing | 0.60-0.70 | 0.004 | 0.50-0.60 | 0.004 | 0.30-0.35 | 0.0025 | 0.15-0.35 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.10-0.20 | 0.002 |
| Black crushed stone and black gravel surfaces without surface texturing | 0.50-0.60 | 0.004 | 0.40-0.50 | 0.005 | 0.25-0.30 | 0.003 | 0.12-0.30 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.08-0.15 | 0.002 |
| Crushed stone and gravel pavements | 0.60-0.70 | 0.004 | 0.55-0.60 | 0.0045 | 0.30-0.32 | 0.003 | 0.15-0.35 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.10-0.15 | 0.002 |
| Improved soil | 0.40-0.50 | 0.005 | 0.25-0.40 | 0.005 | 0.20 | 0.003 | 0.12-0.30 | 0.001-0.004 | 0.20-0.50 | 0.0025 | 0.08-0.18 | 0.002 |

**Table 1** presents the values of the friction coefficient at a vehicle speed of 20 km/h for tires with standard tread patterns. Friction coefficient values at other speeds are as follows:

$$\varphi_w = \varphi_{20} - \beta_\varphi (V-20) \tag{2}$$

where
$\beta\varphi$ - speed adjustment factor for friction characteristics (depending on pavement type and condition);

$\varphi_{(20)}$ - friction coefficient at 20 km/h;
V- vehicle speed.

As shown in **Equation 2,** the coefficient of friction depends on the pavement condition and the vehicle speed. Based on this, the maximum allowable speed on a horizontal section and on an incline, considering the wheel-to-road adhesion and rolling resistance, can be determined as follows **(Kurakina, 2014, Lobanov, 2019)**:

$$H = \frac{m_{20} - f_{20} - i}{m \cdot \beta \cdot \varphi + K_f} + 20 \tag{3}$$

where ($K_f$) is the adhesion weight coefficient (0.5–0.55 for passenger cars, 0.65–0.75 for trucks).

It should be noted that regulatory documents usually provide values of the coefficient of friction at a speed of 60 km/h. In this case, to adjust to a different speed, one can also use **Equation 2** by substituting $\varphi_{20}$ with $\varphi_{60}$, and the speed of 20 km/h with 60 km/h.

$$\varphi_2 = (0.5 - 0.85) \cdot \varphi_1 \tag{4}$$

The condition of road surfaces is assessed by qualitative characteristics: dry, damp, wet (clean and contaminated), snow-covered (with loose snow or compacted snow layer – snow pack), ice glaze, etc.

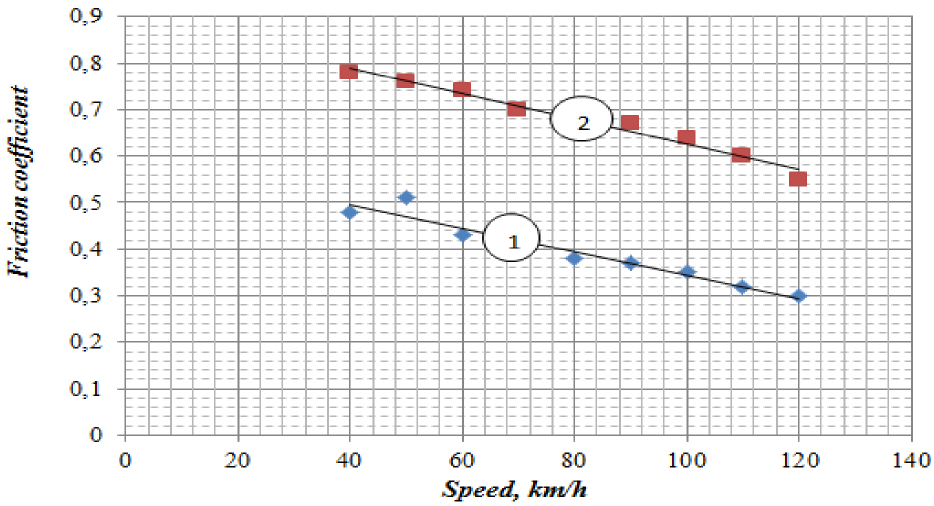



**Figure 3** – Graph of vehicle speed reduction depending on the pavement friction coefficient (author's materials) 1-snow-ice pack; 2- dry pavement (author's materials)

The frictional properties of pavements are primarily determined by surface roughness, which should ensure high friction coefficients ($\varphi_{max}$) throughout the pavement's service life, rapid drainage of water from the roadway, minimal seasonal and cross-sectional variation in the friction coefficient ($\varphi_{min}$), reduced tire tread wear, and an optimal noise level. Pavements whose surfaces have a mean profile depth of at least 1.5 mm best meet this set of requirements **(Kiyalbayev et al., 2020, Yessentay et al., 2021)**.

## 3 RESULTS AND DISCUSSION

The mechanics of snow and ice formations on the highways of Kazakhstan are highly heterogeneous due to the diverse climatic and topographic conditions across the country. Meteorological parameters in the regions depend on the degree of influence and intensity of temperature fluctuations, air humidity, precipitation amounts, as well as wind direction and frequency throughout the winter period. **(Shen et al.,2023, Yashina 2019)**

For example, dry snow pack forms as a result of the rolling and compaction of freshly fallen snow. When a vehicle wheel rolls, the tread points move along cycloidal paths, pushing and dragging air ahead of them. As a result, air becomes trapped in front of the contact patch between the tire and the road, creating a zone of increased pressure. The magnitude of this pressure depends on the wheel diameter, tire width, and the square of the vehicle's speed **(Figure 4b)**.

a)

b)

**Figure 4 –** Snow and ice formations on the pavement surface of the Kostanay-Surgan highway
a – snow cover, section km 40–82;
b – snow pack, section km 89–103 (author's materials)

The hardness of snow increases with its density over time, depending on the air humidity. A decrease in ambient temperature also leads to an increase in snow hardness. As the temperature drops, the hardness of snow increases more significantly with higher density. At a density below 0.200 t/m³, there is no bonding between individual snowflakes. At −20°C, the hardness of unmixed snow is half that of mixed snow. For the same snow density, its hardness increases as the temperature decreases. **(Yessentay, 2021)**

Snow hardness characterizes its resistance to penetration by a solid body. Snow hardness increases as a function of time with increasing density. Lower ambient temperatures also contribute to an increase in snow hardness **(Table 2). Table 3** presents data on snow density, hardness, and shear resistance, which are research results obtained by Kazakh Automobile and Road Institute researchers on the highways of Kazakhstan.

Measurements were carried out on road sections with various types of snow cover and snow compaction under subzero ambient temperatures. Air temperature and snow cover conditions were recorded at the time of each measurement. Snow density was determined using standard field methods by collecting samples of a specified volume and subsequently weighing them, which allowed the assessment of changes in snow density over time.

Snow hardness was measured as the resistance to penetration of a solid body using mechanical penetrometer-type devices. Measurements were repeated multiple times at each site, and the obtained values were averaged. This procedure made it possible to establish the relationship between snow hardness, its density, and the ambient temperature, with the results presented in **Table 2**.

Snow shear resistance was determined by interacting a cutting element with the snow surface. Measurements were conducted at various values of snow density and hardness obtained during field observations. The results of snow density, hardness, and shear resistance measurements are summarized and presented in **Table 3**.

**Table 2**
Snow hardness depending on air temperature (author's materials)

| Temperature, °C | from -1.4°C to -3°C | -6 | -10 | -15 | -18 |
|---|---|---|---|---|---|
| Hardness, MPa | 0.30 | 0.45 | 0.90 | 1.60 | 2.25 |

The theory of particle embedding of friction materials in ice. As shown in **Table 3** and **Figure 5**, at a macrotexture height of up to 1.5–2 mm, a clean embedding of these particles into the tire tread rubber is observed (**Figure 6a**), meaning that the contact area is maximized, and consequently, the adhesion component is also at its maximum.

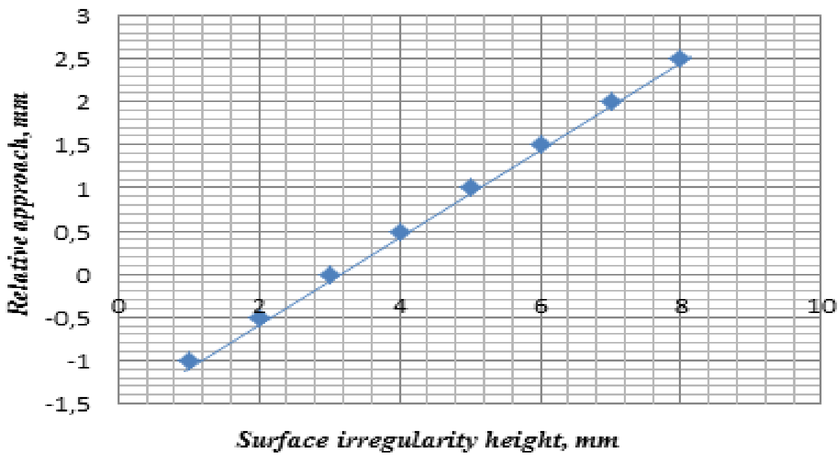
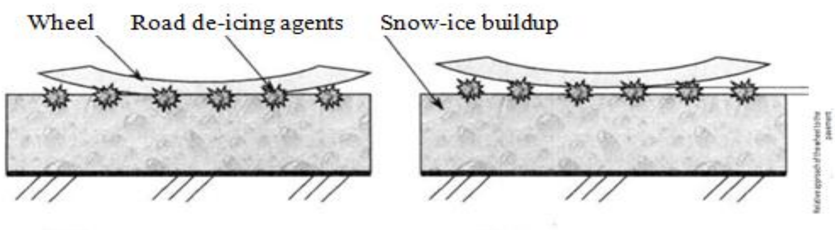



**Figure 5 –** Effect of surface roughness height on the relative wheel-to-pavement contact (author's materials)

**Table 3**
Snow density, hardness, and shear resistance (author's materials)

| Snow cover characteristic | Density, t/m³ | Hardness, MPa | Specific shear resistance, MPa |
|---|---|---|---|
| Very loose, freshly fallen | 0.010-0.200 | 0.02 | 0,001 |
| Loose, weakly compacted, freshly fallen, wind-deposited | 0.220-0.300 | 0.02-0.1 | 0.005-0.01 |
| Compacted, freshly fallen | 0.300-0.400 | 0.2-0.4 | 0.01-0.02 |
| Old, settled | 0.480-0.520 | 0.4-0.5 | 0.025-0.08 |
| Fine-grained avalanche snow, compacted snowpack | 0.550-0.700 | 0.5-0.7 | 0.1-0.5 |
| Snow-ice pack | 0.700-0.950 | – | 1.0-2.5 |

A large macrotexture height will cause the protrusions of the particles to no longer fully embed into the tire tread rubber **(Figure 6 b)**. The tire will roll over them, which consequently reduces the actual contact area. Thus, on snow-covered pavements, the macrotexture height should be maintained up to 1.5–2.0 mm, and taking into account possible surface irregularities and precipitation, up to 3 mm.




a) b)

**Figure 6 –** Variants of wheel-pavement interaction at different roughness heights
a – macrotexture height up to 2 mm;
b – macrotexture height greater than 2 mm **(Kuznecov, 2022)**

Driving conditions during adverse meteorological events are significantly more challenging compared to dry, clean pavements and shoulders. These differences are influenced by several factors, the main ones being the reduction of pavement friction properties depending on vehicle speed and changes in vehicle-road interaction; deterioration of pavement smoothness due to precipitation, ice glaze, fog, high humidity, and other factors. **(Moldamuratov et al., 2022)**

When rain falls, a layer of water forms on the pavement surface, which begins to noticeably affect friction characteristics at film thicknesses greater than 0.2 mm, reducing the adhesive component of the friction force. **(Yespaeyva et al., 2019)**

The coefficient of friction sharply decreases during the initial phase of rainfall when a dense lubricant film forms on the surface. After the dirt is washed away by the rain, the friction coefficient somewhat increases.

In road engineering practice, the reliability of contact between the vehicle tire and the pavement is characterized by the tire's slip resistance on the road surface, which is evaluated by the friction coefficient. **(Kosenko et al., 2019)**

The obtained data indicates the necessity for strict monitoring and speed regulation under winter conditions to prevent accidents related to loss of wheel traction. Special attention should be given to speeds above 40–50 km/h, where friction properties sharply deteriorate, increasing the risk of skidding and slipping. Moreover, the results emphasize the importance of regular application of anti-icing materials to road surfaces, which enhances traction and reduces accident risk. The implementation of adaptive speed limits and informing drivers about road conditions and recommended speeds will help improve traffic safety. It is also important to note that the technical condition of the vehicle, including the selection and proper maintenance of winter tires, plays a crucial role in ensuring adequate traction and safety. Overall, the study confirms that maintains friction properties and ensure safety on winter roads and vehicles.

## 4 CONCLUSIONS

1. The study establishes a quantified relationship between vehicle speed and the reduction of frictional properties on icy pavements. Experimental results demonstrate that friction performance on icy surfaces is significantly lower than on snow-covered or anti-icing treated pavements. A key scientific contribution of this research lies in identifying that the rate of adhesion loss with increasing speed is substantially higher on smooth ice surfaces compared to other winter покрытия types, highlighting the critical role of surface microtexture under dynamic loading conditions.

2. In addition to speed, the study systematizes the influence of tire tread condition, tire pressure, and other operational factors on the friction coefficient. It is shown that tire pressure directly affects the tire–pavement contact area, thereby modifying slip resistance. The research expands existing knowledge by integrating pavement condition classifications (dry, damp, wet, snow-covered, slippery) with dynamic speed-dependent friction behavior, enabling a more comprehensive assessment framework for winter road safety management.

3. A novel practical finding of the study is the quantified increase in braking distance associated with speed growth under winter conditions. The results indicate that at approximately 50 km/h, braking distance more than doubles compared to 20–30 km/h on icy surfaces. This confirms the nonlinear character of friction degradation and substantiates the necessity for adaptive speed regulation models during winter operation.

Thus, the scientific novelty of the work consists in establishing a speed-dependent model of adhesion reduction on winter pavements, identifying surface-specific differences in friction degradation, and providing a basis for dynamic traffic safety regulation under seasonal conditions.

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