

Road surface wear - analysis of tests and possibilities for application of new materials

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ABSTRACT

Wear and tear is a process, which is related with the operation of roads, and regardless of the measures taken to reduce it, this process cannot be completely avoided. The surface layer of the road surface is in continual contact with the vehicle tires of moving vehicles and the impact of aggressive environments of various origins. The efficiency and the safety of road transport depends on several indicators, one of which is the degree of road surface wear. Now only to traffic safety, wear and tear significantly impacts to human health and the environment. In this paper has been conducted an extensive literature review of studies, which are related to road surface wear. New methods and materials to reduce this process are considered. Their results have been analyzed and systematized. Possibilities for using innovative construction materials have been examined, taking into account their specific properties and advantages that would allow their use as part of the road surface, in various facilities, and as road elements.

KEYWORDS

Road surface, wear, self-compacting concrete

1. INTRODUCTION

The road has a complex, multi-layered structure (Figure 1). The top layer is mainly subject to wear, because with this layer vehicle tires come into contact and which is directly exposed to various aggressive environments, especially in winter conditions. Asphalt and concrete pavements are mainly used for road surfaces, but other materials can also be used, such as flagstone, artificial stone, cobblestone, tiles, or bricks.

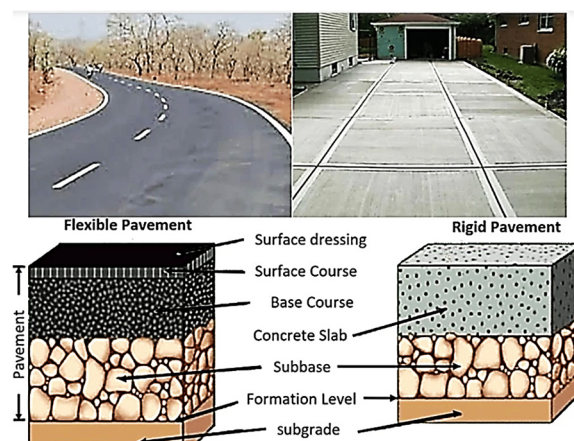


Figure 1: Road structure [1]

The main ingredients of concrete rigid pavement are coarse aggregate, sand and cement. Flexible asphalt pavements are mixtures of mineral aggregates, sand, filler, and bitumen binder. Typically, the coarse aggregate content is around 90–

95% and the bitumen binder around 5–10%. The properties of asphalt can be modified through admixtures such as adhesives, polymers, and various types of fillers. The composition and ratio of materials for two pavement types can vary widely across individual countries and regions.

The friction between the road surface and the tires of motor vehicles is crucial for traffic safety, as it provides the necessary cohesion when driving and braking. On the other hand, as a result of friction, the road surface wears out. This process is inevitable and negatively affects both traffic safety and human health, as well as the environment. In addition to the release of harmful fine particles, wear is also associated with increased noise when driving a motor vehicle. At the same time, it increases the costs of road maintenance and repair.

The number of vehicles and kilometers traveled is increasing every year. Traffic is one of the main sources of particulate matter. Emissions other than those from non-exhaust gases may arise from abrasion of motor vehicle's parts (tires, brake pads, clutch, bodywork, etc.) or from abrasion of the pavement surface, as well as from re-spraying of deposited particles.

The development includes a literature review of studies related to road pavement. The goal is to analyze the results of studying this inevitable, negative process accompanying the operation of roads. Possibilities for using alternative innovative materials, e.g., self-compacting concrete for pavement and road elements, are proposed, taking into account their specific properties.

2. ANALYSIS OF RESEARCHES RELATED TO ROAD PAVEMENT

Flexible pavements are multi-layered, often with asphalt concrete as the surface layer. They are the most common type of road pavements due to their lower initial cost and relatively easy maintenance. This kind of pavements provide elasticity and adaptability to the ground, which undergoes expansion and contraction caused by freeze-thaw cycles or minor shrinkages. In contrast, rigid pavements consist of a single layer of reinforced or unreinforced concrete. Concrete pavements are characterized by exceptional durability and have a long lifespan (often exceeding 30 years), but their placing and repair are more expensive than flexible pavements [1].

The wear of road pavements depends on many parameters such as the composition of the mixtures, traffic intensity, atmospheric changes in the environment, the composition and concentration of the aggressive environment used in winter road maintenance, and can vary significantly. The choice of materials for the mixture, as well as the technology of its placing, greatly affects the wear of the pavement and is crucial for its characteristics and efficiency. The distribution of traffic load also affects wear.

The research examined in this article have the aim to study the mechanism and degree of wear of road surfaces. Understandably, most of the researches are related to the wear of flexible pavements, due to their widest application. Some authors report that particle emissions from pavement wear are more difficult to quantify than those from the car tires wear and other vehicle undercarriage components. This is mainly due to two facts: the first one is related to the chemical composition of bitumen, which is complex, obtained as a result of recipe modeling. This fact makes it difficult to quantify its part in the overall chemical balance of the mass of released particles. The second fact is the result of the mixing of primary wear particles with fine road particles [2].

Abrasive wear of the road surface, in addition to endangering traffic safety, leads to the spread of dust pollution in the roadside area. Fine particulate matter can cause harm to people and the environment. Studies of the composition of pollutants have been conducted to determine the size and distribution of particles, and the harm to human health has been highlighted [3, 4]. Some authors [4] believe that the abrasive wear of the pavement depends primarily on several factors, such as: degree of mixing (homogeneity); dimensions of the additive materials, their properties, and the characteristics of the binding component.

In [5], based on testing three groups of samples, it is concluded that the existence of air voids affects abrasive wear by reducing the abrasion resistance of asphalt concrete. This can be explained by the separation of asphalt particles due to a lack of good adhesion between them. The process of weakening the bond between particles can be explained by an elementary mechanical model [6]. On the one hand, the presence of air voids negatively affects some properties of asphalt concrete, such as tensile strength, frost resistance, and fatigue resistance [7]. On the other hand, their reduced content leads to more intense rutting, just like poor compaction [8]. The contradictory influence of air voids in these experiments can be explained by poor compaction and poor homogenization of the asphalt concrete mixture [9]. Experiments in [5] show that the deterioration of the abrasion resistance of pavement materials depends on several processes, including the destruction and cracking of coarse aggregate particles. This imposes limitations on the laying mechanism and especially on the compaction process. It must exclude the destruction and cracking of the particles of the inert material. In [5], a relationship between the type of binder and the abrasive wear of asphalt concrete has been proven. It has been found that the simple abrasive wear model [6] can also explain the influence of the type of binder. For example, bitumen modified with styrene-butadiene-styrene polymer has good elastic properties, and its use reduces the processes of particle separation and cracking by more than 10-20% (Figure 2, c, d) [5].

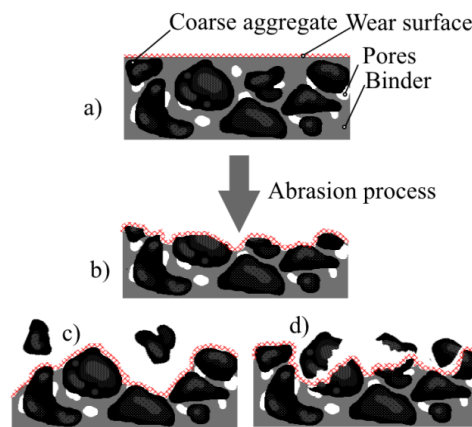


Figure 2: Process of abrasive wear of asphalt concrete:

(a) asphalt concrete before abrasion,

(b) abrasion process with striation,

(c) particle separation, (d) cracking of coarse aggregates [5]

Abrasion resistance also depends on the properties of the pavement materials. The use of coarse aggregates with a larger grain size and the use of SMA (split mastic asphalt) mixtures instead of dense-structure mixtures reduces wear [10].

In [11], to determine the abrasion of the top layer of bituminous pavements, asphalt mixtures from the wearing courses are compared in terms of mechanically separated dust particles. The particle measurements were performed in laboratory conditions, which allowed particle samples to be separated from the road surface only. Distinguishing particulate emissions from road abrasion and re-dusting is very difficult due to similar elemental compositions [12].

The results obtained in the studies in the above-mentioned works show that increased wear resistance can be achieved by increasing the size of the coarse aggregates, using a polymer-modified binder, and reducing the air void content in the asphalt concrete mixtures.

Some publications [13] investigate the noise generated by road surface wear. Noise is an environmental problem that leads to a deterioration in the lifestyle of many people and damage to their health. Outdoor noise usually has levels above 55 dB(A), with road traffic being one of its main sources. There are several options to reduce the noise: building noise barriers; insulating facades - an effective way in densely built-up areas; reducing noise in the car engine, and last but not least, taking measures to reduce the noise generated by the interaction between the tire and the road surface. It has been established that when the vehicle is moving at speeds between 30-45 and 120 km/h, this noise dominates. In [13], low-noise road surfaces are considered as an important factor in reducing road traffic noise. The surface of the pavements is a crucial factor that ensures noise reduction or amplification. The most common types of asphalt pavements with low noise levels are thin asphalt pavements and porous asphalt. Porous asphalt pavements reduce noise levels due to the high percentage of air voids in them [14]. Tests conducted in [15] found that thin-layer surfaces wore out very quickly and had a shorter life compared to porous asphalt pavements. However, the results in [16] show that porous asphalt pavements tend to lose their noise reduction characteristics after two to three years, which is assumed to be due to pore clogging. Another type of low-noise road surfaces are poroelastic pavements. They consist of granulated rubber or fibers that are combined with a binder. In this pavements the air void content is usually between 30 and 40%. The sound absorption as well as the noise reduction of poroelastic surfaces are very high. The introduction into operation of such pavements has not been successful to date [17], which is a result of: lack of adhesion between the surface and the sublayer; poor wear resistance; poor friction on a wet surface; high costs; and not good fire resistance.

Optimizing the texture of asphalt mixtures is the most sensible solution for creating low-noise pavements. The rough texture increases vibrations and noise-generating mechanisms. With the smooth surface with high porosity, there is a significant noise reduction. Finding an asphalt mixture that ensures the preservation of these characteristics in the long term is a challenge. Especially in regions with cold winters and high precipitation levels, where are used studded winter tires. Steel studs have a highly abrasive effect and cause mechanical wear on the road surface during the winter season. In such regions [18], to avoid abrasion, dense asphalt mixtures with a larger coarse aggregate size - D_{max} 16 mm - are usually used. However, noise measurements in these regions show that the noise levels increase with increasing D_{max} . To achieve noise reduction, it is recommended that D_{max} be reduced [16]. At the same time, as D_{max} decreases, pavement wear increases [19], leading to shorter pavement life and more health problems caused by dust formation due to abrasion. The challenge is to find the right balance and choose a grain size that provides good wear resistance and leads to positive acoustic characteristics of the road surface.

A significantly smaller proportion of the developments are aimed at studying rigid pavements.

The durability of the concrete pavement surface, including its wear resistance and material durability over time, is the subject of research in [20]. The wear of the concrete pavement surface is a function of both the cycles of repeated tire loading and the number of freeze/thaw cycles in the presence of de-icing chemicals. Heavy truck tires, tire chains, and studded winter tires cause significant damage even to high-quality pavements [21]. Studies have shown that ruts as deep as $\frac{1}{4}$ to $\frac{1}{2}$ inch (6–12 mm) can appear in just one winter in regions where typically 30% of passenger cars are equipped with studded tires [22]. This quickly deteriorates the pavement surface, causing road safety problems.

There is ongoing research and development to create more wear-resistant concrete coatings [23], such as polymer-cement concretes, ultra-high-performance concretes, self-compacting concretes, etc. One aspect of quality is the amount of calcium hydroxide in the hardened mixture, which is directly related to the water/cement ratio – the so-called water-cement ratio (w/c) – used in the concrete [24]. This product of the cement hydration process is soft and erosive, often resulting in microscopic pits in the surface of the concrete.

Freeze/thaw resistance is also affected by the water/cement ratio, as it determines the size of pores and other voids. The total amount of pores include gel pores, capillary pores, and air voids [25]. Typically, concrete with low permeability (i.e., low water/cement ratio) is able to withstand freeze/thaw cycles better than concrete with a higher w/c. The water that enters the pores, as a result of freezing, expands and increases its volume by about 10%. This leads to the appearance of significant internal stresses, which destroy the concrete structure and lead to a violation of the integrity of the road surface [26]. After several freeze/thaw cycles, the local scaling of the surface results in direct exposure of the concrete to water penetration and aggressive salts [27].

Some of the research is aimed at studying different patterns of abrasive wear of concrete. In [28], a theoretical model based on test results of abrasion caused by the movement of detached particles transported by water is presented. The study shows that the mass loss in concrete can be expressed as a function of the work done by the abrasive mixture and a parameter related to the resistance of the concrete. Another study that extends this theoretical model, the loss of material, besides as a dependence on the composition of the concrete, is also expressed as a function of the abrasion effect caused by the rolling wheel and the total abrasion time [29].

Researchers are hampered by the fact that, in some cases, contradictory requirements are placed on them. For example: the mixture should have sufficient aggregate size to ensure good adhesion, but not too much so as not to increase noise; it should be well compacted to ensure good adhesion, but not too much so as not to damage the integrity of the aggregate; the binders should have good adhesion properties and at the same time not pollute the environment, etc.

This requires a continued search for new road surface materials.

3. SELF-COMPACTING CONCRETE - POSSIBILITIES FOR ITS USE AS AN INNOVATIVE MATERIAL FOR PARTS OF THE ROAD PAVEMENT, IN VARIOUS FACILITIES AND ROAD ELEMENTS

The search and work on creating new materials that will maximally satisfy the conditions that road pavements must meet, continues. To solve with some of the above-described problems about rigid pavements, the so-called self-compacting concrete (SCC) can be used. Invented in Japan [30], this type of concrete is suitable for use in elements with a high percentage of reinforcement and in facilities where a denser structure of the finished elements is required. Studies of its applicability show very good resistance to the effects of aggressive environments due to its denser structure. A study was conducted in [31], which showed that elements made with SCC have a longer life compared to those made of ordinary concrete when treated with aggressive anti-freeze mixtures in winter.

In rigid pavements, the increased size of the coarse aggregates is a prerequisite for the formation of cavities around the larger grains of the aggregate, which creates ideal conditions for water ingress and the destruction of the pavement according to the mechanism described above. To solve this problem, the size of the coarse aggregates can be limited to 20mm or 16mm, as recommended in the SCC formulations [32, 33].

The main advantage of rigid concrete pavements, namely their significantly greater load-bearing capacity, can be further developed by working towards increasing the adhesion between concrete and reinforcement under dynamic loading conditions. Studies in this direction have been conducted, and the results are presented in [34, 35], which prove that due to its denser structure, SCC has better bond strength to reinforcing steel than ordinary concrete, with this difference reaching up to 7%. At the same time, it has been found that when treated with an aggressive environment, SCC shows higher strength and durability compared to ordinary concrete compositions at the same water-cement ratio. The difference reaches up to 12%, which makes the SCC compositions suitable for use in constant and/or periodic exposure to aggressive environments [35]. Laboratory studies of the abrasion resistance of concrete show that it depends on the hardness of the binder, the type of coarse aggregates, and the strength of the bond between the coarse aggregates and the binder on the one hand and the bond strength between the concrete mix and the reinforcing steel on the other [35].

Optimal limits for the volume of the total amount of paste and the ratio between the additives have been established to achieve maximum resiliency and stability of the concrete mix, which guarantees its dense structure, preventing water and aggressive agents from entering [36, 37].

The above mentioned studies show that SCC has properties that make it applicable for road surfaces.

4. CONCLUSION

Researches related to road surface wear has been studied and systematized. Important characteristics and their influence by factors such as formulation composition, grain size, presence of air voids, frost resistance, noise generation, etc. have been identified.

Due to its good mechanical characteristics, SCC is increasingly entering construction. Studies related to the development of SCC with different formulation compositions have been studied. It has been established that its properties, such as a very good dense structure that prevents the entry of water and aggressive agents, which provides it with durability and a longer life, as well as its significantly greater load-bearing capacity, make it a suitable material for road surfaces.

The results of the studied tests [30-37] provide grounds to propose the use of SCC for parts of the road surface, as well as for various elements and facilities on the road. Researches should continue with a different formulation, with the emphasis on its properties essential for its application as a road surface.

Given the growing amount of household waste, when experimenting with new formulations, it is good to emphasize the use of recycled materials in their composition, especially those with low toxicity. This will lead to saving large amounts of energy, as well as reducing the consumption of natural resources for the production of new materials.

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