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Green technologies pavement construction

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Abstract
The article deals with the problem of the negative impact of road traffic on the environment. An attempt has been made to justify the need to modify the current technical and material requirements for the construction of road pavements in view of the dynamic growth of road traffic and the increase in freight transport. The attention is focused on the effectiveness of modern and environmentally friendly asphalt pavements. The presented technologies include recycling, polymer modified asphalts, asphalts modified with rubber granules, examples of environmentally friendly pavement constructions and non-standard (also known as "special") pavements. The article concludes with a summary of relevant practical considerations.

Keywords: Pavements, Environment, Technology, Ecological solutions

1. REQUIREMENTS FOR PAVEMENT STRUCTURES IN THE FACE OF INTENSIVE TRAFFIC GROWTH

The impact of transport and road infrastructure is considered in terms of a number of effects, of which the environment is only one [6]. Fig. 1 shows a general classification of impacts and their interrelationships. The terms 'setting' and 'environment' are distinguished to signal a formal separation of the physical area around the road from the way it is used, and the spatial impact of transport on the natural environment and human living conditions.

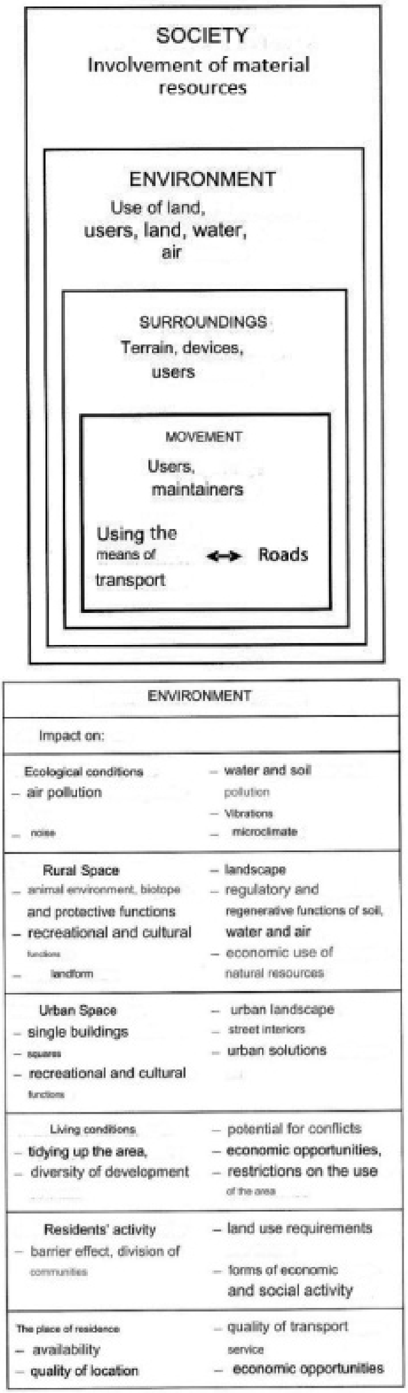

Fig. 1: The areas of traffic impact and their characteristics [6]

The measurements, studies and analyses of road transport as well as the observations of the impact of road transport on the environment testify to the validity and importance of the problem, which has grown dynamically and on a global scale, particularly over the last 30 years. The results presented in almost every report on the environmental impact of road transport point to the serious risks associated with noise emissions, air pollution and their effects on vegetation, fauna, soil, groundwater and surface water [6, 8, 22].

Until now, the general technical requirements for road pavements, currently classified as "road classics", have been formulated by W. Grabowski [8] in two general sets "A" and "B" (Fig. 2). In view of the intensive growth of freight and passenger traffic, increasing vehicle loads, high-speed passenger traffic and the need to reduce the environmental impact of traffic, it is necessary to update "the classic" (meaning "the basic") technical requirements. In this context, the evolution of road surface requirements is presented below (Fig. 3) [8].

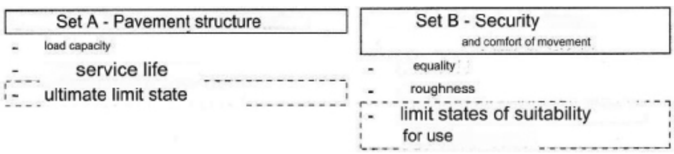

Fig. 2: Basic technical requirements for road pavements [8]

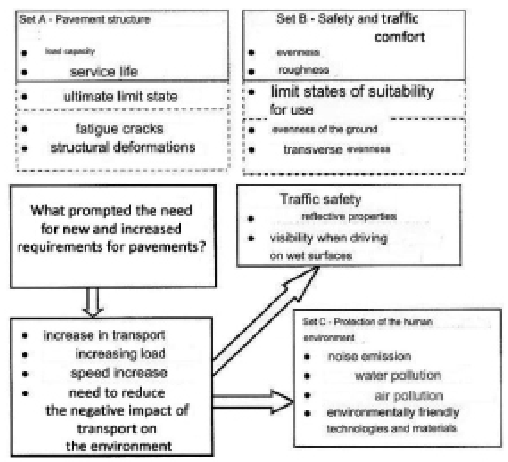

Fig. 3: Evolution of road pavement requirements [8]

In the „A" set (in the modified technical requirements), an ultimate limit state has been introduced. This condition is regarded as exceeded if the pavement develops fatigue cracks of at least 20% of its surface area or structural deformations of at least 12.5 mm in depth [8]. In the „B" set, additional serviceability limit states have been introduced, defined by the values of the following parameters: longitudinal evenness, transverse evenness, and skid resistance. The road safety requirements have been extended. These include: the reflective properties of the pavement, the provision of visibility when the vehicle is moving on the wet pavement, as well as the micro and macro texture characteristics of the pavement [8]. The need to reduce the negative impact of transport on the environment leads to the need for a third set of requirements. This set (marked „C") includes the requirements for the reduction of noise emissions, the reduction of groundwater pollution, the use of environmentally friendly materials and technologies and the rational use of industrial waste [8].

2. ENVIRONMENTALLY FRIENDLY PAVING TECHNOLOGIES

2.1 Asphalt pavement recycling

Recycling in the road industry refers to the reuse of mineral and bituminous mixtures incorporated into road pavements. In Poland, the recycling method was developed in the mid-1990s. The use of recycling, i.e., the reuse of materials after modification, leads to a reduction in the consumption of asphalt and aggregates and a reduction in the energy intensity of repair work. In general terms, recycling consists of scarifying or ripping out the existing pavement layer, adding new components (mineral and bituminous mixtures or asphalt), mixing them on-site or off-site, i.e., in a mineral and bituminous mixture production unit, and then placing and compacting them into the pavement structure [2, 3, 4, 11, 17, 18, 19, 27, 28].

In addition to the economic benefits, the main advantages of recycling are [8÷10, 19, 22÷26]

- the possibility of increasing the bearing capacity of the pavement without increasing its thickness,
- elimination of the so-called rebound cracks that appear in the wearing course placed on the damaged pavement (rebound cracks appear in the wearing course as a result of their penetration from the direction of the lower pavement layers or the substructure),

- the possibility of repairing the substructure (if it is found to be in an unsatisfactory technical condition),
- in the case of a multi-lane road, the possibility of local repair, i.e., repairing only one damaged lane, without having to apply an overlay over the entire width of the road,
- curbs, gullies and manholes can be left at their existing height.

The undoubted contribution of road recycling technology to the protection of the natural environment is the elimination of the need to collect waste materials from used pavements [8÷10, 19, 22÷26].

Depending on the temperature, bituminous pavement recycling methods are classified as: cold, and hot [19]. With regard to the place where the asphalt mix is processed, a distinction is made between recycling [19]:

- using stationary asphalt mixing plants (recycling in aggregate paving plants)
- in situ (i.e., on the road).

Only the surface course can be recycled, in which case it is referred to as surface recycling, or the surface course including binder course and substructure (deep recycling). The national road industry [3, 8, 17, 19, 22] divides recycling methods into three groups: surface recycling, hot recycling, and cold recycling.

Hot recycling with mineral and bituminous mix units involves [19]:

- ripping up the existing (damaged) asphalt pavement,
- crushing the recovered mix,
- feeding the recycled material into the units that produce the mineral and bituminous mixes,
- incorporating the resulting mixes into the pavement.

The optimum recycled material content is 15-20%, but it is possible to produce mixes containing up to 70% recycled material [19].

Cold recycling is a method of repairing asphalt pavements with either crushed stone or natural stone aggregate substructures [19]. Existing asphalt pavement layers, including some or all of the substructure, can be cold recycled directly at the site of the road to be repaired or in stationary mineral and bitumin mixing plants. The technology is similar to soil stabilisation with binders. The process is as follows [19]:

- The material obtained from the pavement (known as asphalt milling) is crushed and mixed with a bitumen component (asphalt or asphalt emulsion) or other binder (cement, lime or fly ash); the result is an increase in strength (compressive, tensile and shear), bearing capacity (ability to take increased service loads) and resistance to weathering;
- The modified asphalt milling is incorporated into the substructure layers,
- The substructure can be covered with one or two layers of a mineral-asphalt mixture or with surface stabilisation, depending on the traffic load (seven traffic categories are provided in the road classifications prepared by the Technical Universities of Gdansk and Wroclaw on behalf of the General Directorate for National Roads and Motorways in 2013 and 2014).

Finally, it should be emphasised that a closed-loop economy is one of the basic principles of the environmental policy. The reuse of materials also reduces the consumption of energy and natural resources, which ultimately makes the technology of reusing mineral and asphalt mixes potentially significant in terms of environmental protection and reducing the consumption of petroleum-based materials in road construction [21].

2.2 Modified bitumens

The aim of the modification is to improve the performance of mineral asphalt mixes and extend the life of the pavement by increasing the viscoelastic range of the asphalt. This requires increasing the resistance of these mixes to permanent deformation, cracking, fatigue, ageing and external influences. Here are some types of modifiers [3, 17]:

- Polyester fibres 7% by weight, polypropylene 6%, mineral wool 6%, cellulose 0.3%;
- Sulphur,
- Trinidad asphalt 40% (containing volcanic ash),
- Fillers (mineral meal 40%, coal dust 15%),
- Polymers 2-12% by weight.

The ideal asphalt should have an almost constant consistency at temperatures ranging from about (-20)°C to +80°C [3].

Polymer modified asphalts, i.e., artificial plastics (polymer asphalts), can be divided into two main types [3]:

- elastomeric asphalts (asphalts modified with polymers from the elastomer group),
- plastomeric asphalts (asphalts modified with plastomeric polymers).

There are significant differences between elastomeric and plastomeric asphalts, partly due to the mode of action of the polymer in the asphalt [2, 3, 17]:

- elastomers form a spatial network within the asphalt; they have elastic and thermoplastic properties,
- plastomers do not form a network, but dissolve in the asphalt and remain suspended in it, increasing its viscosity.

A prerequisite for the use of a polymer as an asphalt modifier is asphalt's compatibility with the polymer, i.e., their ability to mix. Polymers are classified according to the way they harden [2, 3, 17]:

- thermoplastics: they soften when heated and harden when cooled,
- thermosets: they harden irreversibly when exposed to high temperatures or chemical agents (chemically cured).

Selected types of road asphalt produced in Poland are listed below [1, 2].

- **Bitumen D50 RG.** Used as a binder in asphalt concretes used for road pavements with increased performance requirements**.**
- **Asphalt D70.** Used in road construction for the construction of carpet roads, base and binder layers of open or semi-compact asphalt concrete in two or more layer asphalt pavements and for the production of sand asphalt mixes.
- **Asphalt D200.** Used for "sealing" pavements, regeneration of deteriorated pavements and surface dressing; for mixing gravel, crushed stone and clay; for all asphalt macadam works; for the production of asphalt mortars (mastics); for the production of asphalt emulsions, and fluxed asphalts.
- **Elastobit 30RG** (SBS-modified elastomeric asphalt). Used for asphalt concrete (AC) as binder course and sub-base; for cast asphalt and thin crack control layers (SAM, SAMI).
- **Elastobit 50RG** (SBS modified elastomeric asphalt). Used for the production of asphalt concrete (AC) for all bituminous layers of road pavements, sprayed mastic asphalt (SMA) and porous asphalt concretes.
- **Elastobit 90RG** (SBS modified elastomeric asphalt). Used for the production of SMA, porous asphalt concretes, ultra-thin wearing courses and anti-crack interlayers.
- **Elastobit 160RG** (*SBS modified elastomeric asphalt. SBS: thermoplastic elastomer belonging to the group of block copolymers of styrene and butadiene.)* Used for surface treatment, insulation and production of asphalt emulsions.

- **Elastobit 80C** (highly modified elastomeric asphalt). Used for asphaltic concrete (ACC) in all bituminous layers of road pavements, surface dressings (SMA) and "hot" thin wearing courses.
- **Elastobit 150C** (Highly modified elastomeric asphalt). Used in road construction for the production of SAMI membranes.
- **ORBITON HiMA Highly Modified Asphalt [2].** ORBITON HiMA asphalts (HiMA - Highly Modified Asphalt or HPM - Highly Modified Mixes in the USA) are a family of asphalt binders with superior functional properties, modified with a high content of a new type of polymer, more than 7% m/m, which results in a phase inversion in the asphalt/polymer mixture (Fig. 4).

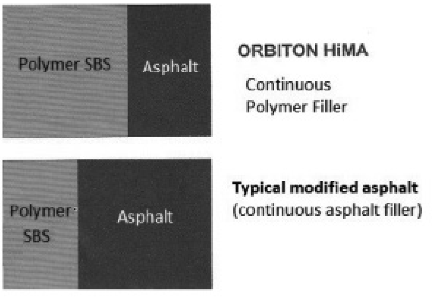

Fig. 4. Differences in the volumetric ratio of asphalt to polymer in asphalt highly modified ORBITON HiMA (top) and typical ORBITON polymer asphalt (bottom) [2]

The ORBITON HiMA road binder, launched by ORLEN Asfalt® in 2014, has the highest softening point and the lowest penetration, i.e., it has properties that counteract pavement cracking and permanent deformation (rutting), and has increased fatigue strength [2].

2.3 Environmental, health and economic issues related to the use of rubber-asphalt binders

According to the authors of the monograph *Właściwości asfaltów modyfikowanych gumą…* [18], asphalt is one of the most environmentally friendly materials. However, the process of producing mineral asphalt mixes requires the use of high technological temperatures, which raises concerns about the emission of harmful compounds. In addition, acknowledging the concerns raised in the past about the emission of harmful gases during the process of rubber modification of asphalt, work was carried out in the USA in the 1990s to determine the harmfulness of this technology [5]. The US National Institute of Occupational Health and Safety (NIOSH) produced a report on the occupational health effects of rubber modification. It concluded that rubber-asphalt technology does not cause adverse health effects in workers, but can be disruptive. The study found no elevated levels of highly aromatic polycyclic hydrocarbons, benzene, sulphur compounds or carcinogenic effects.

German studies [16] have shown that the use of mineral-rubber-asphalt mixtures does not give rise to different types of vapours and aerosols compared to conventional mineral asphalt mixtures. A German study measuring gas emissions during the production of mineral asphalt mixes with the addition of rubber asphalt mix milling showed that emissions at the stack in the plant were no higher than during the production and recycling of conventional mineral asphalt mixes [18].

The database on the performance and economics of rubber modified asphalt pavements collected over the last few decades makes it possible to estimate the main physico-mechanical parameters of the improved pavements. These parameters are the following: increased resistance to cracking (fatigue, rebound and low temperature) and increased resistance of the pavement to permanent deformation [28]. Fig. 5 shows a comparison of the crack resistance of conventional (HMA) and rubber asphalt mix (AR mix) pavements [28]. Other commonly cited benefits of rubber mix pavements include:

- reduced costs for repairs, resurfacing and ongoing maintenance,
- good vehicle wheel grip on the surface
- reduced noise at the tyre/road interface.

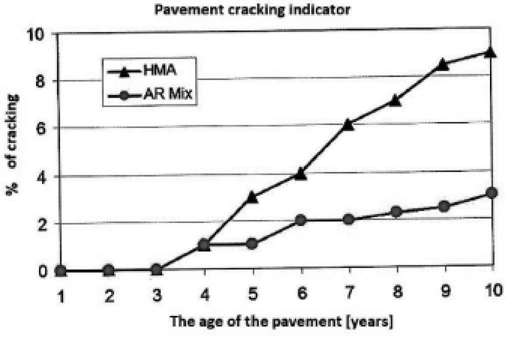

Fig. 5. Comparison of crack resistance of conventional (HMA) and mineral-rubber-asphalt mixes (AR mix) [18, 28]

Rubber-asphalt mineral mixes containing porous asphalt or discontinuous aggregate mixes with increased void content can be designed with higher binder content than conventional mixes (i.e., without rubber), as the increased binder viscosity allows the thicker asphalt film to remain on the aggregate surface without excessive ‚flow'. This maximises the resistance of rubberised mixes to cracking. However, such a process has the effect of increasing the cost of mix production. Nevertheless, the increased cost of producing these mixes is offset by the significantly longer life of the pavement and reduced maintenance requirements. This makes rubber surfacing technology a cost effective alternative for road construction [28].

Long-term observations show that properly designed and constructed miner- al-rubber asphalt mixes are an effective alternative to polymer modified asphalt mixes and are highly cost competitive when considering the life cycle of the road project [15, 18, 20, 28].

2.4 Examples of green solutions in pavement technology

Binder asphalt concrete (BAC) in the binder course [13]. It is a composite material that allows for the disposal of asphalt waste, such as the asphalt milling coming from the recycling of deformed bituminous layers of road pavements. BAC is a binder course placed on a sand-cement mix substructure. The wearing course is asphaltic concrete. The BAC layer is composed of 85-90% bitumen asphalt milling (e.g., mastic asphalt) mixed with 15% cement sand mortar (c:p=1:1, cement 7.5% and sand 7.5%). Advantages: high stability, strength, resistance to deformation under heavy traffic loads. Pavements made with BAC have the characteristics of semi-rigid structures, so they can be used in locations subject to significant deformation caused by heavy traffic and in countries with hot climates. Examples of applications in Poland are the pavements of bus stops in Lublin. Observations carried out on these facilities have confirmed the absence of damage, particularly transverse cracking, and the very good evenness of the slab.

Pavement with lower layers of high modulus asphalt concrete (Pl.: BAWMS). This type of pavement, which is used in France and the USA (Arizona), has been implemented in Poland since 2000 with the participation of the Road and Bridge Research Institute [8, 22÷26].

The pavement structure consists of:

1. A thin wearing course (2 cm thick) of a discontinuous aggregate mix (SMA or MNU), which provides
   - good roughness (it is necessary to use an aggregate resistant to polishing and to roughen the fresh layer with fine gravel),
   - considerable durability due to the thick binder film on the aggregate grains,
   - high resistance to low-temperature cracking and surface fatigue cracking (a new phenomenon caused by the passage of vehicles with wide tyres and increased pressure),
   - no risk of deformation of this 2 cm thick layer with 0/8 mm or 0/12.8 mm aggregate (it is therefore unnecessary to require the rutting resistance for this thin layer),
2. A thick lower binder course (or courses) of high stiffness modulus asphalt concrete to provide resistance to deformation, safe absorption of traffic loads and fatigue resistance.

Whitetopping technology proven in Europe and used in Poland [8, 22÷26]. A solution used to reinforce existing bituminous pavements where deep ruts occur. Whitetopping does not require demolition of the pavement and involves placing a layer of concrete on top of the previously levelled bituminous pavement. It is very popular in Belgium. An example of its use in Poland is the concrete overlay on National Road 81, Żory in Upper Silesia.

SMA wearing course with low viscosity modifier [8, 22÷26]. SMA is generally produced at a temperature of around 180o C. The technology used to produce SMA is therefore not environmentally friendly as it is quite energy intensive and produces significant greenhouse gas emissions during the production process. In order to properly construct the wearing course and ensure adequate durability, the average paving temperature of the SMA mix should be around 140o C. However, the nature of the investment process in the road construction industry often requires paving works to be carried out at quite low ambient temperatures. Under such conditions, the mix cools rapidly during transport from the mixing plant to the site and during the paving process. Lowering the average embedding temperature of the SMA mix below the 140o C limit increases the viscosity of the asphalt, which causes difficulties in compaction (rolling with a roller) and consequently the wearing course does not achieve the required minimum 98% compaction. Ultimately, the result is a loss of resistance of the wearing course to the effects of water and frost and accelerated deterioration.

The low viscosity modifier added to the SMA mix reduces the required compaction temperature of the mix (below 140o C) and provides an improvement in the mechanical properties of the wearing course, i.e., resistance to permanent deformation (rutting). In addition, the low viscosity modifier introduced into the asphalt ensures a reduction in the production temperature of the SMA mix (below 180o C) and thus a reduction in greenhouse gas emissions, which is important for environmental protection.

Binders characterised by special resistance to rutting [8, 19, 22÷29].

Foamed asphalt [29] - a cold applied binder (classified as a composite material) consisting of asphalt (97÷98%) and steam (1÷3%). It was invented in 1957 in the USA (Iowa). The intensive development phase of foamed asphalt technology is considered to begin in 1991, after the Mobil patent was disseminated.

Multigrade bitumen:

- Multigrade KSLA Shell (Multiphalte): Developed in the KSLA Shell laboratory in the 1980s, without polymer modification. Obtained by a special process from crude oil with suitably selected ingredients.
- Multigrade UNIBIT 35/50, produced at the Gdansk refinery, is characterised by a wide temperature range with no change in the physical properties of the binder (high softening point and low embrittlement temperature).

Rubber-asphalt binders: have many positive characteristics compared to standard binders, e.g., thermal stability, improved elastic properties. Among these binders, the following deserve special attention:

- SAMI-G (Stress Absorbing Membrane Interlayer), which is a mixture of mineral and bitumen with the addition of rubber dust. It is used in the road industry as a separation layer to prevent the initiation of rebound cracks in the upper layer of the pavement from the lower layers of the pavement substructure. It is also used in the rehabilitation of deteriorated concrete pavements and long-term stone pavements. In these cases the mix forms an „overlay”, whose thickness depends on the required reinforcement of the pavement structure.
- SMA-G mix (with rubber dust) used as a wearing course for pavements. Significant measurable benefits of rubber-asphalt binders include noise reduction of up to 9 dB and improved road safety through reduced braking distances.

Asphalt modified by the addition of a chemcrete component [8, 19, 22÷26]. Chemcrete-Concentrate (CCC) was developed in the USA by Chem-Crete Corporation, Menlo Park, California. When added to asphalt, it stiffens the asphalt by polymerisation. The main advantages of asphalt with Chemcrete (6.3%) are resistance to ageing, reduced sensitivity to temperature changes and high resistance to permanent deformation (e.g., rutting).

Green binders [8, 19, 22÷26]. The special solvent-free, cold-applied binders Bioflux and Bioflex (elastomer-modified), developed in France in 1997, are also worth mentioning, as they can replace the fluid asphalts used in surface treatment techniques.

2.5 Special road surfaces

Special pavements are those which are subjected to particularly heavy traffic loads and special climatic conditions. Special pavements also include non-standard structures such as drainage and retention pavements.

Drainage pavements (porous pavements; in the USA and UK the term is „porous asphalt" [8, 9, 10, 12, 17, 22], in the Netherlands porous asphalt is called ZOAB - „Zeer Open Asphalt Concrete" [12]) absorb water from precipitation and prevent it from stagnating on the road surface. According to [17], drainage pavement technology dates back to the second half of the 1970s (USA). In Europe, porous pavements have been used since 1977 (France) and in the following years in Belgium, the Netherlands, Sweden, Austria, Germany and the United Kingdom [17]. However, publications [12, 14] state that porous asphaltic concrete was first used in the UK in 1967 on airport runways as a 10 mm thick ‚anti-skid' layer to further reduce aquaplaning and water spray. In the 1990s, drainage structures were used extensively in France, Denmark, Belgium and the Netherlands (W. Grabowski) [8-10]. D. Sybilski [22÷26] also gives examples of their use in Poland. The advantages of these pavements include [17]: significant resistance to permanent deformation, roughness, permeability and rapid drainage during rainfall, reduced traffic noise. Resistance to permanent (plastic) deformation is demonstrated by an increase in rutting in the pavement of less than 0.5 mm in one year of use [17]. This resistance is determined by the composition of the mineral asphalt mix in the wearing course. The durability of a drainage pavement depends largely on the properties of the binder. For this reason, modified binders mixed with natural rubber, SBS elastomer or rubber mastic are often used instead of road asphalt [10].

In terms of roughness, a drainage layer may have a lower roughness immediately after construction than a traditional bituminous concrete pavement due to the presence of a thick film of asphalt binder on the aggregate grains [17]. However, this film wears away in the porous mix: in the case of asphalt it wears away within three months of use, and in the case of polymer asphalt it wears away after the first year of use. At this point, the roughness of the drainage pavements increases and is comparable to that of conventional pavements. German experience shows that after five years of service, the roughness of drainage pavements is above the required roughness. Moreover, the US experience shows that drainage pavement layers have improved skid resistance at high speeds on wet pavements.

Traditional bituminous pavements are known to be impermeable. Minor irregularities in the pavement cause water to be retained, which can cause a vehicle wheel to aquaplane [17]. In contrast, a drainage pavement, due to the high openness of the structure, allows water to flow inwards and then down the lower impermeable layer to the shoulders [17]. The pores in the drainage layer form channels that carry the water away. The elimination of aquaplaning and improved visibility for vehicles driving on wet pavements is achieved by using a permeable surface course with 20-25% voids [8÷10, 22, 27]. Fig. 6 shows the construction of a drainage pavement (so-called single layer) with a 4 cm-thick surface course of a porous mineral-asphalt mixture using polymer-modified asphalt [9]. Positive results from the operation of drainage pavements have been demonstrated, including in Belgium, where rubber fines from used car tyres, added at a rate of about 18% by weight, were used as an asphalt modifier [8, 22]. It has also been found [17] that, for example, a 4 cm layer with a porosity of 25% can store up to 10 mm of precipitation. According to [17], the thickness of a single layer drainage layer is 4-6 cm. A suitable lateral slope of the sealed layer below (sealing can be achieved, e.g., with asphalt emulsion) allows water to drain to the roadside [17].

The permeability of porous pavements is not constant over time and decreases as a result of mineral and organic contaminants that enter the drainage layer during the life of the road. Therefore, after several years of use, drainage layers need to be cleaned using special machines that exert considerable pressure on the pavement [4, 17].

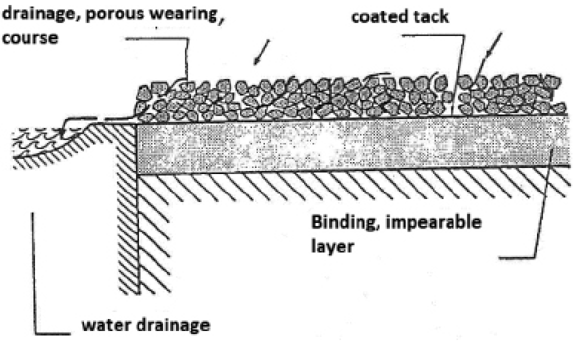

Fig. 6. Vertical section through a drainage pavement
The construction includes a 4 cm surface course of a porous mineral and asphalt mix [8, 9]

Attempts have been made in the Netherlands to solve the problem of the decrease in permeability of drainage pavements as a function of time by using two-layer drainage pavements [8÷10]. A diagram of a two-layer porous pavement (according to W. Grabowski) is shown in Fig. 7 [8, 9]. Components of the modified (two layer) construction:

- Top layer fine grained with 2/5 and 5/8 mm gravel (dirt migration to the interior is hindered),
- Bottom layer coarse with 11/16 and 16/22 mm grit.

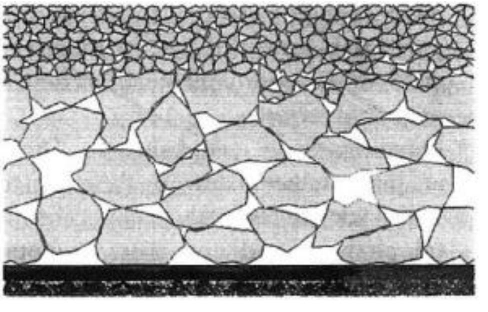

Fig. 7. Diagram of a modified two layer drainage pavement (Netherlands) [8, 9]

The total thickness of the two-layer drainage structure is 7-10 cm [17]. The positive features of porous pavements include a significant reduction in traffic noise. The voids in the drainage mix structure have noise-absorbing properties. Fig. 8 shows, according to [8, 9, 27], the variation of traffic noise as a function of driving speed for three types of pavements: drainage pavement (1), asphaltic concrete pavement (2) and cross-grooved cement concrete pavement (3). It is clear from the graphs that the noise reduction effects are greatest for vehicle traffic on drainage pavements.

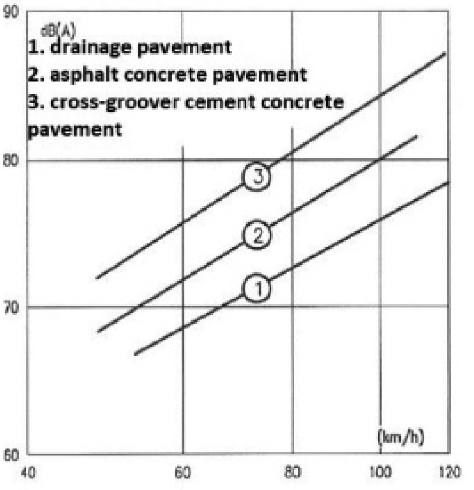

Fig. 8. Road noise intensity as a function of vehicle speed for the three pavement types [8, 9, 27]

On the other hand, Fig. 9 shows the results of tests on the maximum noise level of tyre of the vehicle wheel-road system for a statistical passenger car at a speed of 90 km/h on different road surfaces [17].

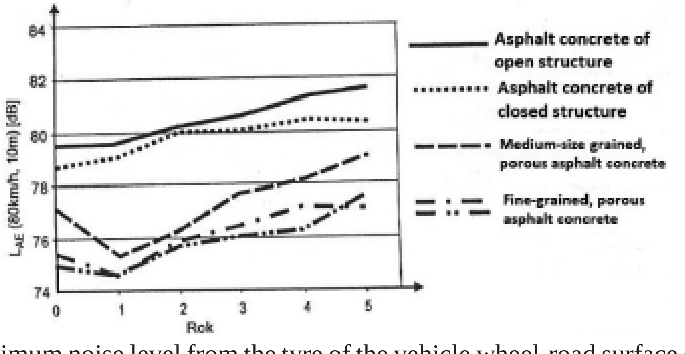

Fig. 9. Maximum noise level from the tyre of the vehicle wheel-road surface system for a statistical passenger car at 90 km/h on different road surfaces [17]

In addition to single-layer and double-layer drainage pavement structures, road sections are known from engineering practice where the entire pavement structure (up to 50 cm thick) consists of porous asphalt mixtures [17]. Pavements consisting of an asphalt drainage layer based on mechanically stabilised aggregate layers have also been constructed (Fig. 10) [17].

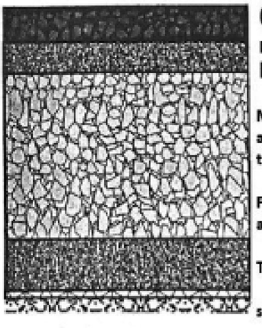

Fig. 10. Full drainage pavement construction - drainage asphalt layer based on unbound aggregate layers on unbound aggregate layers [17]

Studies mentioned in publication [17] show that the optimum thickness of the drainage layer (due to noise attenuation) is in the range of 10÷30 cm.

It is clear that, despite their advantages, drainage pavements also have some drawbacks. The main ones are [17]: reduced durability, increased construction and winter maintenance costs, and limited use. The average service life of drainage pavements is around eight years, with a load of up to 4,000 lorries per day and lane. This compares with 12-18 years for traditional asphalt concrete. The durability of drainage structures is extended by the use of modified binders. The higher cost of drainage pavements is due to the use of larger quantities of high quality chippings and modified asphalt binders for porous mixes. The higher maintenance costs are due to the large amount of winter maintenance required. Ice and snow are distributed more quickly on the drainage pavement due to its high porosity. As a result, a greater amount of de-icing material is used throughout the year than when maintaining traditional road surfaces. With regard to restricted use, drainage pavements should not be constructed on, among others [17]:

- insufficiently stable substructures
- road sections with frequent braking, acceleration, turning and parking,

- longitudinal gradients of more than 10% and horizontal curves with radii R < 75 m,
- stretches of road where the surface is exposed to pollution from moving lorries serving industrial plants,
- roads used by agricultural tractors working in the fields surrounding the road,
- where flooding of the carriageway occurs,
- roads with a speed limit of 55 km/h
- drainage sections of less than 100 m.

The second type of special surfacing discussed in this article is the **retention surfacing** (***chaussees reservoirs)*** [8÷10, 22]. The purpose of their construction on large impermeable surfaces (e.g., shopping centres, large car parks, airport terminals) is to retain as much rainwater as possible (summer storms, etc.) and then discharge it to downstream systems at a rate compatible with the capacity of the existing sewer network [7÷10].

In publications by W. Grabowski (e.g., [8, 9]) three types of retention pavements are presented (Fig. 11):

- Type A: the upper layers of the pavement are made of impermeable (classical) mineral-asphalt mixes, gravel substructure, pipe drainage; easy to maintain construction and suitable for heavy traffic,
- Type B: drainage top layer, reducing vehicle noise, construction capable of absorbing heavy traffic,
- Type C: fully porous construction, allowing direct filtration of rainwater; recommended for lighter traffic loads.

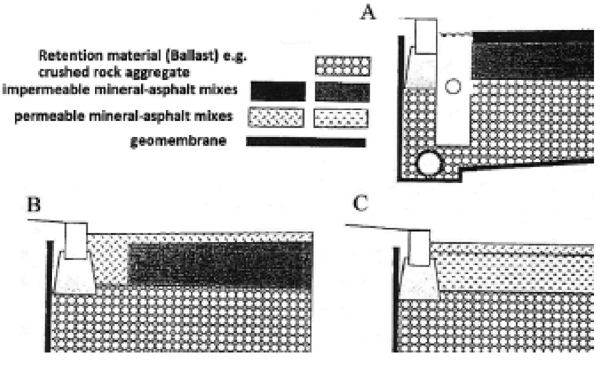

Fig. 11. Three types of retention pavement design (France, USA) [8]

- The retention material (ballast) is 20/70 mm stone ballast with a free space content of 35-45%. The retention pavement is a multifunctional structure because [7÷9]:
  - it allows the movement and parking of vehicles
  - it restricts (throttles) the flow of water during heavy rainfall
  - it reduces the amount of pollutants entering the sewerage system.
- The drainage of water from retention pavements is carried out in two ways [8, 9]:
  - slowing the flow of rainwater by direct infiltration into the ground, where permeable soils of sufficient thickness are present,
  - the separation of the lower layer of the substructure by means of a geotextile saturated with asphalt emulsion (creating a watertight screen), where the subsoil is impermeable. In this case, the water is drained through a system of 100 and 150 mm diameter drains.

CONCLUSION

Today's requirements for the design of road surfaces include both technical requirements (the aim of which is to achieve suitable surface properties and ensure adequate durability) and requirements relating to the comfort and safety of road users and, at the same time, to the protection of the environment. In this context, the Polish road construction industry has been performing difficult tasks within the framework of adapting the condition of roads to the increased requirements resulting from the dynamically growing volume of traffic, as well as new requirements related to membership of the European Union. One of the basic tasks is to strengthen the pavement structure to withstand axle loads of 115 kN and to meet technical and environmental requirements (e.g., pavement roughness, evenness and noise reduction). This requires considerable financial resources, but also the use of innovative material and technological solutions [8, 22].

Observing the development of structural and technological solutions for asphalt pavements, it can be concluded that modern technologies, new materials and products make it possible to meet new, increased requirements for these structures. At the same time, it is hoped that the requirements for the protection of the human environment can be better met.

The use of porous pavements makes it possible to meet environmental requirements by reducing road noise emissions and effectively increasing road safety.

The construction of retention pavements reduces the pollution of water run-off from roads and yards [8, 22].

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