Durable high strength cement concrete topping for asphalt roads

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Abstract. Work on improving riding qualities of pavements by means of placing a thin cement layer with high roughness and strength properties on the existing asphalt pavement were conducted in Ukraine for the first time. Such pavement is called HPCM (High Performance Cementitious Material). This is a high-strength thin cement-layer pavement of 8-9 mm thickness reinforced with metal or polymer fiber of less than 5 mm length. Increased grip properties are caused by placement of stone material of 3-5 mm fraction on the concrete surface. As a result of the research, the preparation and placement technology of high-strength cement thin-layer pavement reinforced with fiber was developed to improve friction properties of existing asphalt pavements which ensures their roughness and durability. It must be emphasized that HPCM is a fundamentally new type of thin-layer pavement in which a rigid layer of 10 mm thickness is placed on a non-rigid base thereby improving riding qualities of asphalt pavement at any season of a year.

1. Introduction

In recent years, road pavement operation conditions have been significantly complicated due to increased traffic intensity and traffic volume. Main roads are exposed to extremely high loads where over 70% of domestic transit is carried out in addition to internal transportation. As a result, traffic intensity on such roads grow at average by 15-20% a year, while on the local roads the growth is within 1-2% [1].

All this leads to deformation and destruction of road pavements.

Pavements which are designed for smaller loads do not withstand current traffic demand that results in deformation and destruction occurrence on the pavement.

It should be noted that the increase in traffic intensity, especially in the number of speed cars, reduces roughness of pavements, i.e. reduces grip coefficient which results in the decrease of traffic safety and leads to emergency situations on the roads.

The experience of leading countries such as USA, Japan, Germany, Sweden, France [2, 3] showed that the use of this type of pavements (international name is HPCM - High Performance Cementitious Materials) will lead to increased roughness, strength and durability of existing asphalt pavements and can be considered as a feasible and economical way of road conditions improvement.
2. Justification of the research related to placement of a thin-layer cement pavement (HPCM)

Thin-layer cement pavement (HPCM) is a strong cement pavement of 8-9 mm thickness reinforced by metal or polymer fiber of less than 5 mm length. Increased grip properties with the car wheel is reached by placing the stone material of 3-5 mm fraction on a concrete surface.

The purpose is to improve roughness and durability of existing asphalt pavement.

Placement of a thin-layer concrete pavement on the existing asphalt pavement is a fundamentally new type of pavement that provides adhesion with existing asphalt pavement and is characterized by increased roughness due to stone material distribution, as well as by waterproofness, crack resistance and durability.

HPCM is a workable type of pavement and it virtually does not involve compaction (roll-on by lightweight rollers). Laying is performed by stackers like placement of guss asphalt mix with simultaneous distribution of stone chippings.

Currently, asphalt pavements are the most widespread out of high performance road pavements [4]. In the USA and CIS countries asphalt pavements make more than 90% of high performance pavements over the total road length carrying over 40% of freights. In Western Europe, asphalt pavement roads make more than 97% of high performance pavements over the total road length.

The researchers [6] believe that roughness is a goodness of fit criterion of asphalt pavement performance properties. It is known that the design speed and traffic safety level are provided at high values of evenness, roughness, wear resistance and grip of the car wheel with the surface of pavement.

One of the up-to-date application directions is a placement of cement pavement over the existing asphalt pavement.

It is known that cement pavements have lower technical characteristics than asphalt pavements in terms of evenness and serviceability but their durability is higher.

Cement pavements have better performance at high loads, especially in summer at high temperatures.

Wearing course of cement mixture ensures better safety and riding comfort for road users and provides sufficient grip values. Experience shows that the combined use of different materials such as cement and asphalt produces a positive effect and provides rigidity and durability of road pavements.

In the project “Long-life surface for busy roads” by the Transport Research Center of the OECD and the International Transport Forum [8] main advantages of HPCM pavement type were determined. Laboratory testing of the HPCM matrix for compressive strength, tensile strength and modulus of elasticity indicated the material can be characterized as High Strength/High Modulus. The results indicate HPCM wearing courses will have good bonding properties as well as durability, confirming these objectives have been achieved.

Testing at medium scale demonstrated that a durable bond between asphalt binder course and HPCM can be established, provided the asphalt surface prior to paving of HPCM has been carefully scarified and cleansed. It is also critical for this asphalt to be in the high range regarding E-modulus and temperature resistance.

The conducted surveys in Ukraine have shown high adhesion of HPCM layer with asphalt layer. Despite complicated traffic conditions, the pavement performs satisfactorily. In this area cracks and other deformations do not occur[9].

Testing has shown that HPCM has great strength and integrity. It is clear that certain requirements need to be met – including a strong and even lower layer and careful embedding of chippings – to ensure maximum performance.

This structure can be used for heavy and intensive traffic on the main roads that connect big cities, industrial centers, airports on the way to cities, etc. Experience on such pavement design application was summarized by Concrete Roads Committee jointly with Non-Rigid Pavements Committee established at PIARC (The World Road Association). This pavement design was named as composite (complex) by the Committee; Italian experts called it multifunctional, i.e. each layer in this design performs only its assigned function.
Asphalt pavement is heated because of its dark color. HPCM pavement is lighter by shade, so it isn’t heated so much. Thus, asphalt concrete of lower pavement layer doesn’t undergo plasticity deformations.

Pavement design including asphalt layer and HPCM wearing course performs as a monolith layer, so the dilatation joints are not arranged.

Considering HPCM’s simplicity and workability at placement, such material should be made widespread.

3. Pavement (HPCM) characteristics

Works on the development of a mix design and placement technique for a thin layer cement pavement (НРСМ) considering local features and the use of constituent native materials are currently underway in Ukraine.

Constituent materials of cement mix are the following:

- Fibers - fibers of various origins (polymer, metal, glass fiber, basalt fiber);
- Stone materials - granite gravel of 3-5 mm fraction;
- River sand - moisture of 9%;
- Cement - CEM-400, CEM-500 brand with addition of superplasticizers;
- Water for cement preparation.

Due to the fact that works on (HPCM) mix design were performed under an international program but taking into account local features and presence of domestic materials, attention was paid mainly to the choice of a fiber type – a fiber to be used for dispersion reinforcement of cement material.

Types of fibers existing in Ukraine were selected and the studies of their physical and mechanical properties were conducted. They included the following:

- Steel
- Glass fiber (alkali resistant)
- Basalt
- Asbestos (chrysotile)
- Polypropylene
- Polyamide

Basalt fibers have the highest tensile strength and elastic modulus values. Considering that basalt has other positive physical and mechanical properties such as chemical resistance, frost resistance, resistance to aggressive medium (alkaline and acidic) and its fibers placed in concrete articles have ability to limit cracks propagation in concrete, such material was taken for further research.

3.1. Determination of an optimal cement mix design

In the study, the fibers that are chaotically distributed in cement and sand mixture and used as reinforcing additives are considered as the additives regulating physical and mechanical properties of the HPCM layer.

Mix design was determined basing on the results of defining an optimal number of dispersion reinforced additives.

Dispersion reinforced additives were introduced directly into cement and mixed and than sand components of a concrete mix were added to the composite cement.

An optimal concrete mix design per 1 m³ of concrete is the following:

1) with addition of coarse basalt fibers (CBF)
   - cement - 494 kg/m³
   - CBF fiber - 38 kg/m³
- sand - 1368 kg/m$^3$
- water - 170 l/m$^3$

b) with addition of fine basalt fibers (FBF)
- cement - 486.4 kg/m$^3$
- TBF fiber - 13.6 kg/m$^3$
- sand - 1400 kg/m$^3$
- water - 168 l/m$^3$

3.2. Determination of physical and mechanical properties of the resulting mix design

The research performed at the laboratory of DerzhdorNDI. Comparing the research results with those performed at the laboratory of LCPC (France) showed some identity of mix designs despite the fact that French researchers used metal fibers of d = 0.2 mm, 13 mm length and PVA of d = 0.33 mm and 15 mm length.

It should be noted that basing on DerzhdorNDI’s experience of work with dispersion reinforced materials it can be stated that the fibers used at the LCPC laboratory were too big by length that would not provide sufficient workability at the preparation of a cement mixture. In this case uneven distribution of fibers may occur.

Therefore, our studies were conducted with the fibers of not more than 4 mm length.

The optimal concentration of fibers in mixtures was determined experimentally. For coarse basalt fibers it was 2.8% for fine - 4.4% of cement weight. Samples compaction was conducted by vibrocompression. Frost resistant was determined at -5 -20 temperature and thawing in water and in 5% solution of NaCl. Water resistance was determined by the standard method before occurrence of "wet spots" on the samples. Wear was determined in cm after 840 rotations in "LKI-3" circle, impact strength was studied at Page’s copra.

Basic physical and mechanical properties of dispersion reinforced cement mixture are shown in Table 1.

Analysis of data presented in Table 1 shows that basalt fibers based additives allow getting cement material of improved strength, density and frost resistance that will positively affect the riding qualities of road pavements.

| Table 1. Physical and mechanical properties of materials for HPCM pavement. |
|---|---|---|---|---|---|---|
| Indicators | Measuring unit | Initial with addition of coarse basalt fibers CBF | with addition of fine basalt fibers FBF | Steel Glass fiber (alkali resistant) | Asbestos (chrysotile) |
| Density | kg/m$^3$ | 2200 | 2400 | 2600 | 2700 | 2600 | 2500 |
| Porosity | % | 2.0 | 1.0 | 1.3 | 1.5 | 1.1 | 1.3 |
| Fiber content | % | - | 2.8 | 4.4 | 3.5 | 3.0 | 3.5 |
| Compressive strength | MPa | 54.0 | 68.0 | 62.0 | 55.0 | 61.0 | 62.0 |
| Tensile strength (axial tensile) | MPa | 6.0 | 14.0 | 12.0 | 10.0 | 11.0 | 12.0 |
| Water resistance, after 28 days | % | 0.8 | 0.3 | 0.4 | 0.5 | 0.5 | 0.4 |
| Strength on impact | J/cm$^3$ | 2.6 | 3.2 | 2.98 | 2.84 | 2.75 | 2.9 |
| Wear, after 840 rotations | cm | 0.08 | 0.04 | 0.03 | 0.04 | 0.04 | 0.06 |
| Frost resistant coefficient after 200 cycles in water | | 0.95 | 1.00 | 1.0 | 0.93 | 0.92 | 1.0 |
4. Conclusions

1) Theoretical research, preliminary study of repair work experience in the leading countries of the world and performed laboratory research showed that HPCM pavement is a new promising type of pavement to increase durability and roughness of the existing upper asphalt layer. Such pavements are not widespread in Ukraine yet.

2) The optimal type of fibers to be added to the cement mixture for dispersion reinforcement is basalt (coarse and fine fibers) that are available in sufficient quantities at industrial enterprises of Ukraine.

3) Adding of basalt fibers allows getting a cement mixture with improved physical and mechanical properties and durability; it imparts strength to cement pavement, provides resistance to dynamic load impact, improves tensile resistance, impact strength. Roughness of (HPCM) is ensured by the application of stone chippings.

4) Along with high physical and mechanical properties, dispersion reinforced cement pavements are characterized by rapid growth of strength regardless of temperature and ambient moisture, low water adsorption and high resistance to acids and alkali solutions.

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[9] Звіт про виконання науково-дослідної роботи 2011 Розробити рекомендації, технічні умови та технологічні карти на влаштування тонкошарового цементного покриття (HPCM) для підвищення шорсткості і довговічності існуючого асфальтобетонного покриття Київ /Develop recommendations, specification and flow chart on placement of thin-layer cement pavement (HPCM) to increase roughness and durability of existing asphalt pavement/ Report on R&D work performance (Kyiv)