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Analysis of durability testing of concrete landscaping units

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HIGHLIGHTS

- Freeze-thaw resistance is the one of the main characteristics evaluating durability.
- Top paving layer affects the splitting tensile strength results.
- Abrasion resistance depends significantly not only on the cement content.

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ABSTRACT

In recent years the problem of the durability of vibrocompacted concrete products (landscaping elements, paving blocks in particular) has received great attention in Europe. In Easter Europe there are rather aggressive climate conditions (temperature fluctuations, humidity, precipitation, etc.). Besides, in winter concrete paving is treated with sodium, calcium, magnesium chloride salts that accelerate the deterioration of concrete paving block structure. European standard EN 1338:2003+AC:2006 that sets forth the basic requirements and test methods for concrete paving blocks does not take into account the performance of concrete products under specific climatic conditions. Therefore, it is important to determine the basic technological factors that influence the quality of vibrocompacted concrete, in particular freeze-thaw resistance, and to optimize the composition and other technological properties of vibrocompacted concrete. The freeze-thaw resistance of concrete has to be measured by different methods. The present paper describes the testing of concrete paving blocks, the top layer of which contained different amounts of cement ranging from 527 to 385 kg/m^3. The cement content in the bottom (support) layer compositions of all specimens remained the same – 371 kg/m^3. Density, freeze-thaw resistance according to two different methods, splitting tensile strength and abrasion resistance were measured in the tests.

1. Introduction

Concrete paving blocks are made by means of automated vibrocompaction technology, which involves almost complete displacement or air and a high degree of compaction. In this process the total porosity of concrete products is reduced to the highest extent and consequently water absorption is decreased. Water absorption rate influences the deterioration of concrete products as a result cyclic freezing and thawing in the cold season. Nowadays concrete block pavements have become an attractive engineering and economical alternative for flexible and stiff pavements. The properties such as strength, durability and aesthetically pleasing surfaces have made paving blocks attractive for many commercial, municipal, industrial surroundings and places such as parking areas, pedestrian walks, traffic intersections, and roads [1]. This type of paving is evaluated for being a hard surface which is aesthetically pleasing, comfortable to walk on, trafficable, extremely durable and easy to maintain. Paving blocks are manufactured in factory conditions, ensuring consistency and accuracy. After being situated with an edge restraint over a granular bedding course, individual blocks interlock and act compositely, thus ensuring even distribution of large loads. According to the requirements, concrete paving blocks are categorized into classes that are used for labelling. According to the class of the required resistance to atmospheric effects, it is recommended to ensure the durability in the country on whose market the product will be used [2]. The control of porosity parameters and entrained air content in concrete mix is essential in the manufacturing of concrete paving blocks; besides, higher freeze-thaw resistance requirements are applied for concrete paving blocks depending on the conditions where they are used [3]. Concrete pores can be closed by means of additions supplementing the concrete mix (the number of capillary pores will reduce and the number of closed pores will increase) and thus

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the durability of concrete will increase. Fine-grained structure enables to produce paving blocs of the most intricate form. Paving blocks are usually manufactured in two stages. Firstly, the form is filled with the bottom (supporting) layer of concrete, which is compacted; afterwards a top (finishing) layer is poured onto the compacted bottom layer. The bottom layer contains coarse aggregates up to 11 mm, the top layer contains only fine aggregates up to 4 mm. These products in Northern European climate zone are often exposed to severe climate conditions and cyclic freezing and thawing; the number of freeze-thaw cycles affects the durability of concrete paving blocks. In cold winter season (3–4 months when the temperature is below 0 °C) de-icing salts and sand-salt mixtures are used to melt snow and ice on roads and walkways. These de-icing mixtures accelerate the deterioration of concrete products [4]. Durability is one of the most important concrete product quality indicators in the Northern part of Europe.

According to Kallipi, the durability indicators of hardened cement stone mainly depend on the amount of cement used and water-cement ratio (W/C); the higher is the W/C, the poorer is the quality of concrete [5]. According to Mehta & Monteiro, the porosity of concrete, water content in the mix, environmental conditions and the type of aggregate are the main factors that influence the behaviour of concrete under cyclic freezing and thawing conditions [6]. Hardened cement paste, mortar and concrete are porous materials susceptible to the penetration of gas and liquids. Pores influence the properties of a material in many different ways. Compressive strength and elasticity are mainly affected by the total pore volume, pore size and distribution in the material, the size of the biggest pores, the form and interrelation of pores. Shrinking is mainly the function of energy exchange between the surfaces of pore walls that depends on the total surface area of a porous system. Durability depends on the resistance to freezing and thawing and is controlled by the volume of air entraining pores and the distance between them [7–8]. Water absorption of cementitious systems and resistance to freezing and thawing depends on the size of pores and capillaries, their type and distribution, and the closeness of pores. Closed and small pores do not fill with water completely. The pores that are not completely filled with water are called reserve pores. During freezing, part of the water from completely filled pores can move to these reserve pores and thus make a space for the expansion of ice. Distance between pores must be not big for the freezing water to move from filled to half-filled pores [9]. The resistance of hardened cement paste to freezing and thawing is reduced by open pores and capillaries that are formed after free water evaporates from hardened cement paste. The amount of such pores and capillaries depends on W/C ratio. The more water is added to the cement mix, the more water remains unbound in hardened cement paste and the more open pores are formed after the water evaporates [10].

There are several reasons that cause the deterioration of materials in cyclic freeze-thaw conditions [10–14]:

- Increasing hydraulic pressure of freezing water and subsequent increase in volume;
- Build-up and expansion of ice crystals in capillary pores;
- Osmotic pressure building as a result of the difference of alkali and salt concentration in the liquid phase;

The main cause for the degradation, cracking, scaling and crumbling of concrete is the increasing volume of water that freezes in the pores of concrete products. The density of water is 1 g/cm^3, and the density of ice is 0.917 g/cm^3. Ice takes 9% bigger volume compared to water. Ice crystals exert pressure on the walls of pores and capillaries of hardened cement paste and by expanding can disintegrate the concrete item [15–16]. Ice is a very strong material and its adhesion to hydrophilic materials, such as hardened cement paste, is very strong. W. Micah Hale with co-authors have found that water in capillary pores does not always freeze at 0 °C temperature. The freezing temperature depends on the size and type of pores. When pores are smaller, the temperature required for the pores to freeze also drops. For instance, in pores with the diameter of 10 nm water can remain unfrozen at −5 °C, whereas in pores with the diameter of 3.5 nm water will not freeze until the temperature drops to −20 °C [17–18]. Disintegration of hardened cement paste as a result of freezing and thawing is the most common case for the destruction of concrete products. Water-saturated hardened cement paste exposed to cyclic freezing and thawing can disintegrate like any other mineral solid body [10]. Surface scaling and cracking is the main type of deterioration of concrete exposed to de-icing salts. The most widely used de-icing salts are: NaCl (sodium chloride), $MgCl_2$ (magnesium chloride), and $CaCl_2$ (potassium chloride). Hardened cement paste treated with salt solutions deteriorates faster in cyclic freeze-thaw conditions due to osmotic pressure that accelerates the destruction process 4–5 times. The effect of de-icing salts is observed in road paving concrete, concrete landscaping elements, etc. [19]. Scientists all over the world conduct tests and experiments with concrete blocks, trying to make them more durable and resistant to atmospheric effects. Most of them are directed to waste materials utilization. There are a number of investigations done on concrete paving by adding marble waste to its composition. It is a popular topic of investigations done in the countries where marble is one of the main drivers of their economy. It is used to replace up to 40% of the coarse aggregate in the mixture [20–21]. There are a number of investigations done on concrete paving resistance to atmospheric causes. Basically, scaling caused by freeze-thaw cycles is the biggest problem. Ice melting salts aggravate this process [4,22]. The effect of osmotic pressure occurs due different concentrations of alkali or salts in the liquid phase when hardened cement paste is exposed to de-icing salts under cyclic freezing and thawing conditions [23]. According to J. J. Valenza II, the osmotic pressure is not the main reason for decreasing durability of concrete subjected to NaCl solution [24]. Researchers Hudec, Kaufmann, Marchand et al. have broadly analysed cyclic freezing and thawing with the use of salt solutions and their effect on concretes and hardened cement paste [23–27]. According to J. Marchand, J. Valenza and other researchers, the biggest negative effect caused by salts under cyclic freezing and thawing conditions is when 3% salt solutions are used [24,26–28]. According to J. Šelih, $CaCl_2$ solution has the strongest destructive effect on cementitious materials [19]. According to Sutter, $MgCl_2$ and $CaCl_2$ salt solutions are the most dangerous for the durability of bridge structures [29]. Researchers believe that pozzolanic admixtures, such as silica fume, fly ash and others are suitable for reducing corrosion of hardened cement paste [30–36].

The purpose of the investigation to determine the concrete paving blocks have top layer is used for different binder content (from 527 to 385 kg/m^3) properties, broken concrete paving blocks into three different density groups (low, medium and high). Identify concrete paving top layer abrasion strength changing amount of cement content, as well as identify, absorption resistance, tensile splitting strength and durability of two different methodology (unidirectional freezing and omnidirectional freezing), and to compare them with each other.

2. Materials and compositions

The following aggregates were used for the tests: granite screening 0/2, sand 0/2, sand 0/4, gravel 2/8, granite rubble 2/8. Portland cement CEM I 42.5 R was used as the binding material. Portland cement characteristics are presented in Table 1. Chemical composition of the cement is presented in Table 2.