Porous Concrete as an Anti–Aquaplaning Building Material

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Abstract. The paper considers the use of porous concrete for the needs of communication construction. For comparison, two sets of concrete, ordinary blend have been developed, which is currently used in Poland as road and porous concrete, which is used by Americans in the United States. After concrete testing, moulding and care of the samples under laboratory conditions, compressive strength tests were started after 7, 14, 28, 56 and 90 days. Absorption and capillarity were investigated after 28, 56 and 90 days. In addition, fragments of cubic samples were examined by scanning electron microscopy. Samples measuring 10x10x10 cm were ripened in water at +18 degrees Celsius. Plain concrete has a higher percentage increase in compressive strength than porous concrete. After 90 days, plain concrete had 60.8 MPa strength and porous concrete 22.8 MPa. The carried out tests on absorbability show that the mass increase of porous concrete samples is larger compared to ordinary concrete. It can be concluded from the capillary rising tests that ordinary concrete absorbs less water than porous concrete. Based on the laboratory tests carried out, it was found that porous concrete has a lower compressive strength compared to ordinary road concrete. It is too low due to the use of concrete in the top layer of the road surface. Concrete used for the lowest category of roads, which are municipal roads have a strength of 25-30 MPa after 28 days, while the strength of porous concrete after such time is only 12.5 MPa. In the case of domestic roads, it is 35 MPa, so the only solution is to redesign the composition of the concrete mix. Despite the fact that porous concrete has excellent features for draining water from the surface and can be used as a drainage system in road surfaces (where there is the so-called aquaplaning phenomenon), on parking lots, large flat surfaces it cannot be used due to the very low durability at squeezing, which does not meet the requirements of municipal roads.

1. Introduction
Drainage surfaces are an example of rare road surfaces, despite their many advantages, but also disadvantages associated with the road maintenance standard, they pose a great challenge for engineers, especially in Poland, where this method is little known. Their main advantages are: friendly nature (reduce noise) and an increased standard of safe travel in rainy conditions (they eliminate the phenomenon of aquaplaning). Unfortunately, they also have quite an expensive defect which is the need for strict and demanding maintenance.

2. Porous concrete
Porous concrete for the first time appeared in Europe in the 1980 due to cement shortage and its price during and after World War II. It was used for various construction purposes, including load-bearing walls, filler boards and porous surfaces. Porous concrete is currently used in many cities throughout the
United States, and the number of applications has increased significantly over the last ten years, from road surfaces and pavements for commercial use, [1].

Porous concrete is a concrete mix in which the composition is: cement, fine aggregate, water and possible admixtures. Compared to standard concrete used for road surfaces, the composition lacks small and thick aggregate, this difference affects the nature and features of the porous concrete and allows you to also name it with cavern concrete or porous asphalt concrete.

![A cubic sample of porous concrete](image)

**Figure 1.** A cubic sample of porous concrete [2]

Environmental benefits:
- eliminates residual water on the surface,
- replenishes groundwater,
- prevents penetration of solid suspensions and pollutants into the ground,
- reduces the surface temperature.

Financial benefits:
- eliminates costs for retention basins, curbs, gutters and other water collecting installations,
- in winter conditions usually requires much less salt or other de-icing products than traditional types of surface,
- lower installation costs (there are no underground pipelines, rainwater drainage, or inclination/division into sections),
- low maintenance costs,
- has the same lifetime as ordinary concrete (from 20 to 40 years)?

Important design aspects:
- outflow volume: The porous surface should be properly designed to take into account the amount of water outflow that can occur on the surface. If it is not properly counted, the water level may increase above the surface height.
- due to the fact that the porous concrete has such a high apparent density, and its overall strength is generally lower than in standard concretes, it is not recommended for highways, high-speed roads and places of heavy loading.
- while it is estimated that porous concrete may be two to three times more expensive than ordinary asphalt or concrete, savings are also achieved, as no rainwater installations are necessary [1].
3. The phenomenon of aquaplaning

Aquaplaning, also known as hydroplaning, is a phenomenon that occurs when the water on the surface is not drained from under the tire. Non-supplied water accumulates directly in front of the tire and if its pressure exceeds the tire pressure value on the surface, it loses contact with the surface of the contact surface. In turn, the wheels’ skid and do not react to steering movements, braking and acceleration. As a result, the driver loses control and control over the vehicle, which slips or starts to turn. This is a potentially dangerous situation that affects both the safety of the driver and passengers, as well as other road users.

One of the reasons for the aquaplaning phenomenon is, among others, a significant layer of water on the road surface, which may cause a loss of direct contact of the vehicle with the ground. The water accumulated in front of the tire accumulates because the wheel drives at a relatively high speed into the road surface covered with a layer of water. On the other hand, the pressure of the tire tread on the water remaining at the leading edge of the tire's contact zone with the surface of the tire causes a rapid increase in the pressure of the water being pushed. In a situation where the water pressure exceeds the value of the force with which the vehicle tire presses on the ground, then the tire is in no way able to effectively drain water and the wheel of the vehicle rises, at the same time losing contact with the road surface.

![Figure 2. The phenomenon of normal tire grip and aquaplaning [3]](image)

The greater the amount of water on the surface of the roadway and the higher the speed of the vehicle with which it moves, the more serious the effect and the much more significant weakening of the tire's grip. In order for the tire to guarantee the right performance on a wet surface, where there is a significant layer of water, especially in sections of the roadway, where the slope of the surface is zero, it must effectively drain water and maintain traction.

In a situation when tire manufacturers will not be able to create one that will be able to counteract the phenomenon of aquaplaning, then the challenge is on the side of road construction engineers who will have to create just such a mixture on the road surface that will remove the accumulated layer of water from the roadway, [4-7].

4. The composition of the concrete mix

Preparing for laboratory tests, the first preliminary composition of the concrete mix was created. The mixture was designed using the method of three equations: condition of strength, tightness and water demand. Cement CEM I 42.5R, aggregate from the surrounding mine, rinsed sand, gravel and dolomite grit, as well as chemical admixtures, were used for calculations.

Two comparative compositions of the concrete mix were developed: plain concrete and porous concrete, in order to compare later samples. In the first of them, a standard composition was chosen for road concretes and cement CEM I 42.5 R, sand washed 0/2, dolomite gravel 2/8, dolomite grit 9/16, admixture reducing water, aeration and antispasmodic water. In turn, in the porous concrete, the same cement was used, but only 5/8 dolomite grit and polymer emulsion were used. A concrete mix was made according to the composition found in the second column of table 1.
Table 1. The composition of the concrete mix

| Components | unit of measure | planned concrete mixture composition for 1 m³ | composition of concrete mixture for 1 m³ |
|------------|----------------|--------------------------------------------|---------------------------------------|
|            | regular concrete | porous concrete | regular concrete | porous concrete |
| cement CEM I 42.5R | kg | 360 | 350 | 360 | 350 |
| water | kg | 158.4 | 59.5 | 158.4 | 93.50 |
| sand 0/2 | kg | 601 | - | 601 | - |
| dolomitic gravel 2/8 | kg | 583 | - | 583 | - |
| dolomitic grits 5/8 | kg | - | 1837 | - | 1837 |
| dolomitic grits 9/16 | kg | 637 | - | 637 | - |
| Admixtures | | | | |
| polymer emulsion (BD10 Sika Additive) | kg | - | 52.5 | - | 50 |
| reducing the mixing water, plasticizer | mass of element % | 0.7 | - | - | - |
| aeration (Sika Aer®Pro-3) | mass of element % | 0.18 | - | 0.223 | - |
| antispasmodic | mass of element % | 0.25 | - | - | - |
| w/c ratio | | 0.44 | 0.17 | 0.44 | 0.266 |

5. Compressive strength test on cubic samples
Previously prepared standard cubic samples with dimensions of 10x10x10 cm were subjected to a compression test on a hydraulic press. 3 cubic samples were prepared for each of the tested plain and porous concrete. The test was performed after 7, 14, 28, 56, 90 days from the moment of placing the concrete mixture in standard forms. The tests were carried out at the same hours as the moment of forming the concrete in the days mentioned above in order to obtain the most accurate results. The study was conducted according to the standard PN-EN 12390-3:2002.

Plain concrete has a greater compressive strength increase than porous concrete. As for the shape of the concrete growth line, they are similar to each other. Additionally, it is noticeable that the increase between 56 and 90 days is practically the same. In the case of compressive strength results, concrete after just 7 days had 40 MPa strength, and porous concrete only 11 MPa. The increase in the strength of ordinary concrete is quite dynamic, and the porous concrete slow.
6. Capillary rising test on cubic samples
Cubic samples with dimensions of 10x10x10 cm were used for the tests. The test process consists in placing the prepared samples in a special vessel so that the base is immersed in water to a depth of 2-3 mm. It should be remembered that the water level should be topped up so that the sample is permanently submerged to the same depth. The weight measurement of concrete samples was made before and after the 15 min, 30 min, 1 h, 4 h, 24 h, 48 h and 72 h tests.

It can be concluded from the capillary rising tests that ordinary concrete absorbs less water than porous concrete. Considering the distribution of concrete properties during maturation, it results that for normal concrete capillary rising increases with maturation. After 28 days from making the samples, the test showed the lowest capillary rising rate of 2.65 kg/m², and the most unfavourable sample was after 90 days with the highest value of 3.15 kg/m². However, our research shows that porous concrete does not have such dependence. After 56 days, the water absorption was the highest relative to other test dates and after 72 h was 3.37 kg/m², and the lowest capillary increase was observed on the sample after 28 days.
7. **Absorbability test on cubic samples**

The test was carried out on cubic samples with a side dimension equal to 10 cm. They were carried out after 28 days, 56 days and after 90 days. Initially, the samples were dried and then weighed with an accuracy of 0.1 g. In order to test absorbability, the cubes were placed in a bath tub, so that the distances between the samples were at least 20 mm and the bases were not in contact with the bottom of the vessel. The vessel was filled with water at a temperature of about 20 °C to a half height side of the samples. After 24h the samples were removed from the vessel and then weighed. Over the following days, the samples were completely under water so that the water was at least 10 mm above the upper surface of the sample. The test was terminated after 48h because no further increase in sample mass was observed.
The research shows that the mass increase of porous concrete samples is greater compared to ordinary concrete. By what it can be concluded that the hardiness of ordinary concrete will be better. And the negative impact of de-icing agents used when operating the roadway is smaller. In addition, you can see a drop in absorbability with the time of concrete maturation. In addition, according to the requirements for concrete pavements given in the book by Antoni Szydło [8], the absorbability should be less than 5%. In our case, ordinary concrete meets the set requirements, and porous concrete only after 56 days from the execution of the samples. Therefore, in order for the surface to better withstand the negative influence of variable temperatures (0 ° C passages), the concrete works should be performed as early as possible before the air temperature drops below zero.

8. Scanning electron microscope test
The scanning electron microscopy was carried out in a full vacuum on fragments of cubic samples taken twenty-eight days after forming. A series of photos were taken at various places and close-ups and tests were carried out in several sample areas.

Figure 7. Water absorption of porous concrete samples [%]

Figure 8. Air leach and C-S-H phase in regular concrete, 1000x magnification
Figure 9. Analysis of the chemical composition of the tile shown in Figure 8

Figure 10. Air leach in porous concrete, 1000x magnification.

The analysis of the study showed that the C-S-H phase is on the aggregate surface, i.e. a very stable structure of hydrated calcium silicates, which accompanies the complex hydration process of cement. In the above photograph, the area of strongly compacted needles is visible, which originated from the existing C-S-H phase.

Observing, in turn, the graph in Figure 9, which presents the chemical composition of Figure 8, we note the presence of elements: calcium, oxygen, silicon, aluminium and in trace amounts of coal, magnesium, sulphur and iron. Some of the elements occur in the Portland clinker, which consists of alite and belite, hence the high content of calcium and silicon, tricalcium aluminate, hence aluminium and brownmillerite, hence iron. Alit, belite and water are the reactants resulting in the formation of hydrated calcium silicates and calcium hydroxide.
9. Conclusions

Based on a series of laboratory tests, it was found that porous concrete has a lower compressive strength compared to standard road concrete. It is too small due to the use of concrete in the top layer of the road surface. Concrete used for the lowest category of roads, which are municipal roads have a strength of 25-30 MPa after 28 days, while the strength of porous concrete after such time is only 12.5 MPa which is too little to approximate results to the municipal road standards. In the case of national roads, it is 35 MPa, so the only solution is to redesign the composition of the mixture [9-10].

Further analysis of the porous concrete showed that the dolomite aggregate is too weak to make a concrete mix, because the line of destruction of the samples formed during the compressive strength test is found on the aggregate grains, not in the area where the grains meet, for which the binder is responsible. From this it follows that the change of the aggregate to more durable (granite or basalt) could significantly improve the strength of the concrete.

Despite the fact that porous concrete has excellent parameters for draining water from the surface and can be used as a drainage system in road surfaces (where there is the so-called aquaplaning phenomenon), parking lots, large areas it cannot be used due to very low compressive strength that does not meet the requirements of even municipal roads.

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