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Assessing the abrasion resistance of cores in virgin and recycled aggregate pervious concrete

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HIGHLIGHTS

- Abrasion resistance of pervious concrete was evaluated on core and cast specimens.
- Abrasion was measured by the Rotating-Cutter and the Impact Abrasion methods.
- Mixtures were produced using limestone, pea gravel, and recycled concrete aggregate.
- The Impact Abrasion method had a low within-test coefficient of variation in core specimens.
- Recycled aggregate and GGBFS did not reduce the abrasion resistance of pervious concrete.

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ABSTRACT

Abrasion resistance of pervious concrete was evaluated on core and cast specimens by using the Rotating-Cutter method and the Impact Abrasion method. Sixteen mixtures were produced using limestone, pea gravel, and recycled concrete aggregate, and up to 30% of cement was replaced by ground granulated blast-furnace slag. The analysis of the core specimens indicated that the Impact Abrasion method had a low within-test coefficient of variation and was able to differentiate among mixtures. The use of recycled aggregate and ground granulated blast-furnace slag did not have a detrimental effect on the abrasion resistance of pervious concrete.

1. Introduction

Pervious concrete is characterized by an interconnected network of pores [1], which represent 15–35% [2] of the total volume of the mixture. This property makes it an environmentally friendly paving material, permitting easy passage of water through its porous structure, allowing for infiltration and deep percolation [3]. The benefits of using this material include, but are not limited to, the reduction of storm water runoff, removal of pollutants from water, reduction of noise, improved skid resistance, and potential to mitigate the heat island effect [4–9].

The use of waste materials such as recycled aggregate in pervious concrete further increases its environmental benefits by reducing the amount of materials extracted from quarries and riverbeds. Li [10] and Rizvi et al. [11] substituted 15% of virgin aggregate with recycled aggregate and did not find any significant difference between the mixtures using recycled aggregate as compared to the ones using only virgin materials. Gaedicke et al. [9] replaced 50% of virgin aggregate with recycled aggregate in pervious concrete, which decreased its compressive strength by 8% as compared to virgin pea gravel for a 20% porosity. An additional avenue for further improving the sustainability of pervious pavement is the use of supplementary cementitious materials such as ground granulated blast-furnace slag (GGBFS). While GGBFS can significantly reduce carbon emissions by limiting the amount of cement used in the mixture, replacing up to 30% of the cement with GGBFS does not negatively affect the permeability or compressive strength of pervious concrete [9].

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Despite the environmental benefits of pervious concrete, its lower strength compared to conventional pavements and the lack of standardized test methods for quality control have limited its use to low-traffic applications such as parking lots, roads with minor use, sidewalks, and bicycle trails [12–17]. Whereas the lower strength of a pervious concrete mixture may be alleviated by improving the base or the pervious pavement layer thickness, its surface durability can still be affected by a number of factors [12]. For instance, a poor paste bond can often lead to the disjointing of aggregate particles in the surface of the material [18]. This problem, known as raveling, normally occurs when shear stress is applied to a pavement surface causing the paste-aggregate bond to fail, thus affecting its uniformity and structure. The mixture design, curing method, and placement techniques are some of the other variables that can have a direct effect on the abrasion resistance of a pervious pavement, which determines the likelihood of a raveling incident [23].

A limited number of studies have evaluated the raveling and abrasion resistance of pervious concrete. Henderson et al. [19] performed a visual pavement surface evaluation on pervious concrete pavement test sections that had been subjected to a variety of applications, loadings, rehabilitation maintenance methods, and environmental conditions. They observed that the worst raveling occurred at joints and corners and attributed this finding to the placing of the concrete under colder-than-suggested conditions. Kevern et al. [20] investigated the effect of various curing methods on pervious concrete durability. Surface abrasion was tested using a rotary cutter device according to ASTM C944 on beams constructed to simulate the field construction conditions. They found that the rotary cutter surface abrasion method differentiated between curing methods, allowing for relative comparison of the surface durability. They also found that mixtures cured under plastic sheets achieved higher abrasion resistance than the other surface treatments such as soybean oil, white pigment, and a non-film evaporation retardant.

Several studies have attempted to identify a method that can properly evaluate abrasion resistance on pervious concrete. Wu et al. [21] compared three different test methods, namely the ASTM C944 Surface Abrasion Test, the Cantabro Test using an ASTM C131 Los Angeles Abrasion Machine, and the Loaded Wheel Abrasion Test using the Asphalt Pavement Analyzer [22]. To evaluate surface durability based on the Cantabro loss test, they placed three cylinder specimens, measuring 150 mm in diameter by 100 mm in height (6 in by 4 in), in the ASTM C131 Los Angeles Abrasion Machine (no steel balls) and then subjected them to 300 revolutions. Mass loss ranged from 35% to 80%. The abrasion resistance was also measured on 300 mm by 125 mm by 75 mm (12 in by 5 in by 3 in) beam specimens in accordance with ASTM C944. Additional specimens were used to measure abrasion resistance using the Asphalt Pavement Analyzer, which is commonly used to test the rutting potential of asphalt mixtures. The authors concluded that all three abrasion tests were able to measure pervious concrete abrasion resistance and differentiate among the various mixtures. They also found that the ASTM C944 Surface Abrasion Test demonstrated lower repeatability and higher variability (CV = 32%) compared to the Cantabro Test (CV = 11%) and the Loaded Wheel Abrasion Test (CV = 19%). Finally, they concluded that using 4.75 mm (No. 4) single-sized gradations with latex admixture and polypropylene fibers can improve the abrasion resistance of pervious concrete.

Offenberg et al. [23,24] evaluated surface durability of pervious pavements with a Los Angeles Abrasion Machine, commonly used to evaluate abrasion resistance in aggregates. In this study, laboratory-cast specimens of 100 mm by 100 mm (4 in by 4 in) were cured for seven days and compacted to achieve the design porosity. The specimens were placed in the drum of the Los Angeles Abrasion Machine and rotated for 50, 100, and 500 revolutions. The initial weight of a set of three samples was measured before and after the rotation cycles. Finally, the mass loss was calculated. The authors observed that, after 50 revolutions, there was a modest abrasion of the coarse aggregate. Significant loss of the aggregate was observed after 100 and 500 revolutions. They concluded that an increase in porosity resulted in a higher mass loss percentage for the samples studied.

Finally, Shu et al. [25] evaluated the abrasion performance of pervious concrete in-situ. Cantabro mass loss measured in cores extracted from field slabs was compared to the values obtained from cylinders compacted with the standard rodding compaction method. Cores were found to have higher values of porosity compared to the cast cylinders, which resulted in lower strength and higher values of mass loss.

While the aforementioned research projects provided valuable information on pervious concrete abrasion resistance, additional research is needed to analyze the effect of aggregate type and sustainable materials on the surface durability of pervious concrete. It is also necessary to establish a correlation of the abrasion resistance between cores and cylinders with similar properties.

2. Research objective

The main objective of this project was to characterize abrasion resistance on cores and cast samples of pervious concrete made with virgin and recycled aggregates at different levels of cement replacement with ground granulated blast-furnace slag (GGBFS). Both the ASTM C944 – Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method and the recently developed ASTM C1747 – Standard Test Method for Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion were used to evaluate their effectiveness in pervious concrete and to determine if a correlation between them exists. The effect of specimen type was also analyzed in limestone mixtures by comparing the mass loss of cores against Proctor hammer compacted cylinders of equal porosity.

3. Experimental program

3.1. Materials

The cementitious materials used in this research were Type I Portland Cement and GGBFS. GGBFS is a by-product of steel production and was specifically selected for this study based on previous research that demonstrated its ability to improve workability, increase durability, reduce heat generation, and increase strength for concrete mixtures with a low water cement ratio [26]. The GGBFS had Blaine Fineness equal to 560.5 m^2/kg (835.7 ft^2/lb) and a slag activity index at 7 and 28 days of 98 and 123, respectively; it met the chemical and physical requirements of ASTM C989 and AASHTO M-302 for grade 120.

Three different types of coarse aggregate, namely pea gravel, limestone, and a *recycled concrete aggregate blend* (*RCAB*), were used for this study. All aggregates had a nominal maximum aggregate size of 9.5 mm (3/8 in) and met the requirements of ASTM C33/C33M. Their properties are summarized in Table 1. Pea gravel and crushed limestone were obtained from local quarries in Hays County, Texas. The RCAB was obtained by mixing 50% virgin limestone aggregate with 50% recycled concrete aggregate. Type A mid-range water-reducing admixture and a type S viscosity modifying admixture were also used in this study in accordance with ASTM C 494/C 494M. The admixture dosage used was 392 and 261 ml per 100 kg of cementitious material (6 fl oz/cwt and 4 fl oz/cwt) for the mid-range water-reducing admixture and the viscosity-modifying admixture, respectively.

3.2. Mixture proportioning

A total of sixteen mixtures with a water-cementitious ratio of 0.3 were proportioned using the method recommended by ACI 522-R10 [12]. Two series of batches were produced as shown in Table 2. Series I consisted of nine mixtures with an aggregate-paste ratio of 5.2. One control mixture and two mixtures with increasing